ENGINEERING EXPERIMENT STATION

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FIRST PROGRESS REPORT

INVESTIGATION OF PRESTRESSED CONCRETE
RIDGES

APRIL 1952

UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

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FIRST PROGRESS REPORT

of the

INVESTIGATION OF PRESTRESSED CONCRETE FOR HIGHWAY BRIDGES

Conducted by

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

In cooperation with

THE DIVISION OF HIGHWAYS
STATE OF ILLINOIS

and

THE BUREAU OF PUBLIC ROADS
U. S. DEPARTMENT OF COMMERCE

April 1952

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PREFACE

History

This investigation of prestressed concrete for highway bridges was proposed by the Illinois Division of Highways in October 1950 and a prospectus was prepared by representatives of the University of Illinois in November 1950. The first meeting of the Project Advisory Committee was held in May 1951 and the actual work on the project was begun in July 1951.

Scope

This First Progress Report summarizes the work done through March 1952, and covers a period of about nine months. The work done up to the present time has beem primarily exploratory and preliminary in nature, and has followed rather closely the schedule proposed in the Prospectus.

The work done so far can be devided into three categories: Bibliographical, Analytical, and Experimental. Each of these phases of the work is discussed in a separate section of this report.

Bibliographical

The bibliographical studies have involved a fairly comprehensive survey of the literature relating to prestressed concrete, both in this country and abroad. About 550 references have been read and summaries prepared, while almost 200 additional references have been listed but were not available for study. The object of this study was of course to obtain a more complete knowledge of the work that had been done by others, chiefly as an aid to planning our own investigations. Although the analytical and experimental work on this project is not being conducted in such a way as

to check directly the previous work, it is expected that the experimental results obtained by other investigators can be used with profit as a check on or as an extension to our own program once our knowledge of the behavior of prestressed beams has progressed to a point where the effects of all variables can be evaluated.

The Bibliography is included as Section C of this report. Additional copies have been prepared for distribution to interested groups or persons as approved by the Advisory Committee.

Analytical

The analytical phase of the work has been concerned chiefly with developing methods of computing the ultimate flexural strength of prestressed concrete beams and determining the effects of the more significant variables on this strength. Such analytical studies are almost essential to proper planning of the test program, particularly the choice and range of variables to be included. However, there is another reason for the emphasis which has been placed on the analytical studies. The number and range of variables involved in prestressed concrete beams is unusually large, much larger than for ordinary reinforced concrete. Consequently, it would be prohibitively costly, both of time and money, to attempt a purely empirical evaluation of the effects of even the most significant variables, assuming that one could be certain which variables these were. On the other hand, it is quite convenient and economical to study analytically the effects of many variables, including even quite minor ones, provided only that the method of analysis or computation is reliable and realistic in terms of actual behavior. The approach being followed in this investigation is first to make analyses, based on certain assumptions,

and then to use the results of these studies as the basis for planning tests which have as their primary purpose verification of the analyses and the assumptions on which they are based. It is not expected that the analyses are entirely sound in their present state nor that the assumptions on which they are based are entirely correct or realistic. However, the tests are being planned to provide data for correcting or refining the analyses and assumptions. By these means it is hoped that reliable procedures for predicting ultimate strengths and modes of failure can be developed in a relatively short time and with a minimum number of tests.

The analytical procedures developed for computing the ultimate strengths and modes of failure for post-tensioned, end-anchored, bonded or unbonded, prestressed beams are presented in Section A of this report.

Experimental

The experimental program has been almost entirely exploratory and developmental in nature, dealing chiefly with the problems of manufacturing and testing post-tensioned, end-anchored, bonded beams in the laboratory. In all of this work major emphasis has been placed on producing prestressed concrete beams having certain desired and known or determinable characteristics. No attempt has been made to reproduce in detail any particular system of prestressing, anchoring, or grouting. It has been felt that fundamental studies of prestressed beams would prove in the long run to be of more lasting value than would experiments with particular types of construction that may be popular at the present time. Since most "systems" of prestressing have individual peculiarities which may render the results obtained from tests of any one system not generally applicable to others, it has been felt that all such "systems" should be

avoided. Instead, the experimental and analytical studies are confined at the present time to studies of those variables representing essential differences in the properties and behavior of prestressed concrete beams. These include: pre-tensioning or post-tensioning,

bonded or unbonded,

end-anchored or not,

percentage of reinforcement,

properties of reinforcement,

magnitude of tensioning force,

properties of concrete.

The experimental work described in Section B represents a good portion of the development stage, and we are now ready to manufacture and test beams for the first planned program involving post-tensioned, end-anchored, bonded beams having various percentages of reinforcement. The development work, however, is not entirely completed, and probably never will be, since additional problems will have to be solved as other variables are considered. In particular, additional studies on methods of anchoring the wires for unbonded beams will be required.

Future Work

It is proposed that all three phases of the current work be continued. The bibliography should be kept up to date by studying or at least scanning all new references that are brought to our attention. This will require only a relatively small amount of time.

The tests of post-tensioned, end-anchored, bonded beams should be carried out as planned to investigate the effects of (1) percentage of reinforcement, (2) strength of concrete, and (3) magnitude of tensioning

stress in the wire. It is expected that the completion of this series of tests will require a good portion of the coming year.

In the immediate future, the analytical work should involve chiefly comparisons with the results from the tests and the necessary modifications in the theory or the assumptions. However, additional studies based on various stress-strain characteristics for the reinforcement will probably be required as the scope of the program increases.

Other work being considered at the present time includes a series of tests of beams to determine their strength in shear, and a program of bond tests on various types of prestressing wire, including cables. Development work on methods of anchoring the wire and additional tests to determine stress-strain and creep or relaxation properties of various types of wire will also be required in order to anticipate future programs.

Not all of the work mentioned above can be carried out during 1952-53, but much of it will at least be started if sufficient personnel can be obtained.

C. P. Siess
1 April 1952

SECTION A

PROGRESS REPORT

ON

ANALYTICAL STUDIES OF THE ULTIMATE FLEXURAL CAPACITY OF PRESTRESSED CONCRETE BEAMS

by

D. F. Billet and J. H. Appleton

April 1952

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PROGRESS REPORT ON ANALYTICAL STUDIES OF ULTIMATE FLEXURAL CAPACITY OF PRESTRESSED CONCRETE BEAMS

I. INTRODUCTION

1. Object and Scope of Analysis

An analytical procedure for determining the ultimate flexural capacity of prestressed concrete beams is presented in this report. Both post-tensioned and pre-tensioned beams are considered. Beams may be of the bonded or unbonded type of construction, but the analysis is restricted to beams without compression reinforcement.

The analysis serves two purposes. First, it reveals which variables have a significant effect on the ultimate capacity of prestressed concrete beams, and thus serves as an important guide in the planning of tests. Second, if the test data establish the validity of the analysis either in its original or modified form, the analysis may be used to study the effects of the significant variables on the behavior and load carrying capacity of prestressed concrete beams.

Some preliminary studies have been made of the effects of variations of several parameters which appear in the analysis and of a few important variables. The results are given in the form of non-dimensional curves of the ultimate moment versus a parameter involving the modulus of elasticity and percentage of steel, and the strength of the concrete.

Studies of the limits between various modes of failure complete this report.

2. Modes of Failure of Prestressed Concrete Beams

A prestressed concrete beam may fail initially in flexure, in shear, in bond, or by failure of the anchorage of the reinforcement. Flexural failures may be grouped into three catagories:

a. Failure by crushing of the concrete while the steel is still in the elastic range or has undergone only small plastic deformations. Beams failing in this manner are said to be over-reinforced.

b. Failure by crushing of the concrete after the steel has undergone large plastic deformations. Beams failing in this manner are said to be under-reinforced.

c. Failure by fracture of the steel before crushing of the concrete.

3. Restrictions and Assumptions of Analysis

The analysis is limited to under or over-reinforced beams failing in flexure. Failures by fracture of the steel, bond, or shear are not considered. The analysis was developed for rectangular beams with straight cables; however, it is believed that the expressions derived are applicable also to beams of other cross-sections if the compression area at failure is rectangular. Furthermore, as long as the location of steel at the critical section is the same, the ultimate flexural capacity of bonded beams with curved cables is the same as for bonded beams with straight cables.

The assumptions on which the analysis is based are similar to those used in ultimate theories for ordinary reinforced concrete. Each assumption is discussed separately.

(a) Crushing of concrete at a limiting strain. The analysis is

based upon the supposition that the maximum flexural capacity is reached when the concrete crushes, with the steel stress in either the elastic or inelastic range. It is assumed in the analysis that the crushing of the concrete occurs when the maximum concrete strain reaches a definite value. This value of ultimate concrete strain appears in the equations for ultimate flexural capacity that are developed later.

Several investigations of ordinary reinforced concrete members have indicated that this assumption is justifiable.

(b) Linear strain distribution. Linear distribution of the strains in the concrete from the top surface of the beam to the level of the steel is assumed at all stages. This assumption is required in order to express the strain in the concrete adjacent to the steel in terms of the ultimate strain in compression at the top surface of the beam. Numerous measurements made in earlier tests of both prestressed and ordinary reinforced concrete beams indicate that this is a valid assumption.

(c) No tension resisted by concrete. Tension stresses in the concrete are neglected in the expressions for ultimate strength. Although some tension stresses must always exist, it can be shown that their contribution to the ultimate moment carrying capacity of the beam can safely be neglected in the cause of simplicity.

(d) Stress-strain relationship for steel. It is assumed that the stress-strain relationship for the steel is known. However, in some cases, the actual stress-strain curve of the steel may be approximated by an idealized curve of two straight lines. The inaccuracies resulting from this replacement are discussed in Section 9.

(e) Stress block of the concrete. The concrete stress block at ultimate is assumed to be defined by three parameters k_1, k_2, and k_3

(Fig. A1). The extreme range of these parameters can be estimated fairly accurately but each will have to be evaluated or assumed to predict the ultimate flexural capacity of a beam failing at a limiting concrete strain.

(f) Bond between steel and concrete. The bond condition between the reinforcement and the concrete influences the condition of compatibility of strains.

For beams with bonded reinforcement, perfect bond is assumed to exist between the concrete and steel after the concrete or grout has hardened. This assumption is not strictly correct because local bond failures will occur in the vicinity of cracks. However, this condition is approached when the beam develops many well distributed cracks.

No bond or friction is assumed to exist between the steel and concrete in the unbonded beams. Thus, after tensioning, the total elongation of the steel must be equal to the total elongation of the concrete plus the width of the cracks at the level of the steel.

4. Notation

The following notation has been used in the analysis made in this section. The notation under consideration by the A.C.I. Committee 325 was used where applicable.

General:

A_s = area of tension reinforcement.

b = width of beam.

C = total internal compressive force in concrete (Fig. A1).

d = distance from centroid of tension reinforcement to top surface of the beam.

E_s = modulus of elasticity of steel.

f'_c = compressive strength of concrete in axially-loaded test cylinder.

f''_c = compressive strength of concrete in flexure.

f'_s = ultimate tensile strength of steel.

kd = distance from the extreme fiber in compression to the neutral axis.

$k_1 = \frac{C}{k_3 \, f'_c \, bkd}$, a parameter determining the magnitude of the compressive force C (Fig. A1). It is the ratio of the average compressive stress to the maximum compressive stress.

k_2 = coefficient determining the position of internal compressive force C (Fig. A1).

$k_3 = f''_c \,/\, f'_c$, ratio of compressive strength of concrete in flexure to the cylinder strength.

p = $A_s \,/\,$ bd, steel percentage.

T = internal force in tension reinforcement (Fig. A1).

Stresses and strains at prestress:

ϵ_{ce} = compressive strain in the concrete at level of steel due to effective prestress.

ϵ_{se} = steel strain at effective prestress.

f_{se} = steel stress due to initial prestress force after deduction of all losses, such as creep of steel, plastic flow of concrete, shrinkage of concrete, and elastic deformation of concrete.

Stresses and strains at ultimate:

ϵ_u = ultimate compressive strain of concrete.

ϵ_{cu} = strain in concrete adjacent to the steel at point of maximum moment.

ϵ'_{cu} = average concrete strain over the length of the beam at the steel level at ultimate.

ϵ_{su} = ultimate steel strain at point of maximum moment.

f_{su} = ultimate steel stress at point of maximum moment.

γ = $\dfrac{\epsilon'_{cu}}{\epsilon_{cu}}$, ratio of the average concrete strain at the level of the steel to the maximum concrete strain at that level.

Other quantities are defined in the figures or as they are introduced in the text.

5. Preliminary Analytical Work

During the early development of the theory extensive computations were made of the flexural capacity of bonded and unbonded post-tensioned beams, on the basis of the shape of concrete stress block assumed in Bulletin 399.* In later work, which is presented in this report, the shape of the stress block is disregarded, and the significant parameters k_1, k_2, and k_3 are used to describe the properties of the stress block.

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* University of Illinois, Engineering Experiment Station Bulletin 399, pp. 43-50.

II. DERIVATION OF ULTIMATE LOAD EQUATIONS

An expression for the ultimate moment of a rectangular beam reinforced in tension only will be developed. This expression is valid for all cases considered herein; however, the expression for the parameter q_u is dependent on whether or not the reinforcement is bonded and whether the steel stress at ultimate is in the elastic or inelastic portion of the stress-strain diagram.

6. Ultimate Strength of Rectangular Beams Reinforced in Tension Only

The condition at ultimate at a point of maximum moment is illustrated in Fig. A1. The total tension in the steel is equal to $f_{su}pbd$ and the total compressive force on the section is equal to $k_1k_3f'_cbkd$. The meanings of all symbols are explained in Section 4. The ultimate resisting moment produced by the couple acting on the beam is

$$M_{ult} = T(d- k_2kd) = f_{su}pbd^2(1-k_2k) \tag{1}$$

or

$$\frac{M_{ult}}{f'_cbd^2} = \frac{f_{su}p}{f'_c}\left[1 - k_2k\right] . \tag{2}$$

From the condition of equilibrium of horizontal forces, $T = C$, the coefficient k can be calculated as

$$f_{su}\ pbd = k_1k_3f'_c\ bkd,$$

or

$$k = \frac{f_{su}\ p}{k_1k_3f'_c} = \frac{q_u}{k_1k_3} , \tag{3}$$

where the designation $q_u = \frac{f_{su}\ p}{f'_c}$ is introduced for convenience, and may be interpreted as an effective percentage. By substituting from Eq. (3) for k in Eq. (2), the following equation can be written for the ultimate

strength of a rectangular beam reinforced in tension only.

$$\frac{M_{ult}}{f'_c bd^2} = q_u \left(1 - \frac{k_2}{k_1 k_3} q_u \right). \tag{4}$$

This equation has been developed using only the conditions of equilibrium.

In this equation, the quantities f'_c, b, d, k_2, k_1, and k_3 represent the physical properties of the beam and of the concrete. It is assumed that they are known for any specific beam. The quantity q_u depends on the known properties p and f'_c, and also on the steel stress f_{su}, which is an unknown. Analytical expressions may be derived for q_u from the conditions of compatibility of strain. As the condition of compatibility for bonded reinforcement is different from that for unbonded reinforcement, two separate expressions must be developed for q_u.

7. Parameter q_u from Actual Stress-Strain Diagrams of Wire.

(a) Beams with bonded reinforcement. The steel is assumed to be bonded to the concrete after the steel has been tensioned. In Fig. A2, the strain distribution in the beam is shown at three stages. (1) At prestress, the strain in the concrete at the level of the steel is a compression ϵ_{ce}, and the steel strain is ϵ_{se}. (2) As the load is applied to the beam, the compressive strain in the concrete at the steel level decreases, and at some stage of loading it reaches zero. At this stage the steel strain is equal to $\epsilon_{se} + \epsilon_{ce}$, and the top of the beam is under compression. (3) With a further increase in load, the concrete at the steel level is subjected to tension. The compressive strain at the top increases until it reaches the ultimate value ϵ_u. The elongation at the steel level during the third stage of loading is designated as ϵ_{cu}. Thus

the total steel strain at ultimate may be thought of as composed of three components.

$$\epsilon_{su} = \epsilon_{se} + \epsilon_{cu} + \epsilon_{ce} \tag{5}$$

From the compatibility of strains, an expression for the strain in the concrete adjacent to the steel at ultimate can be written:

$$\epsilon_{cu} = \frac{\epsilon_u (1 - k)}{k} .$$

Or substituting for k from Eq. (3)

$$\epsilon_{cu} = \epsilon_u \left(\frac{k_1 k_3}{q_u} - 1 \right) . \tag{6}$$

Therefore

$$\epsilon_{su} = \epsilon_{se} + \frac{\epsilon_u \, k_1 k_3}{f_{su} \, p/f'_c} - \epsilon_u + \epsilon_{ce} . \tag{7}$$

Whenever equations of compatibility are used in the calculations, the absolute values of strain are inserted into the expressions, the signs having been taken care of in the derivation.

The expression given for ϵ_{su} has been used to solve for the ultimate moment capacity by a trial and error process. Use is made of the actual stress-strain curve of the steel, and the various k parameters are assumed to characterize the stress block of the concrete. The ϵ_{ce} term can be computed by considering the concrete to be elastic at initial prestress. A form of Eq. (7) which was found to be convenient in solving for the ultimate steel stress is

$$q_u = \frac{f_{su} \, p}{f'_c} = \frac{\epsilon_u \, k_1 k_3}{\epsilon_{su} - \epsilon_{se} + \epsilon_u - \epsilon_{ce}} \tag{8}$$

If the computed steel stress does not correspond to the assumed steel strain, another steel strain must be assumed and the process repeated.

(b) Beams with unbonded reinforcement. In a beam with unbonded reinforcement the strain in the steel is the same at all sections along the beam, while the strain in the concrete varies with the moment from section to section. As in bonded beams, strains at three stages of loading are considered: (1) At prestress, the steel strain is ϵ_{se}, and the compressive strain in the concrete at the steel level is ϵ_{ce}. (2) When the concrete strain at the level of the steel reaches zero, the steel strain is $\epsilon_{se} + \epsilon_{ce}$ as before. (3) At ultimate, the maximum strain at the level of the steel is ϵ_{cu}. The average concrete strain over the length of the beam at the level of the steel (including widths of cracks) is called ϵ'_{cu} and equals the change in steel strain since stage (2) because the steel is anchored only at the ends of the beam.

Thus the steel strain at ultimate load may be expressed as

$$\epsilon_{su} = \epsilon_{se} + \epsilon'_{cu} + \epsilon_{ce}. \tag{9}$$

If the ratio of the average to the maximum concrete strain at the level of the steel is designated as

$$\gamma = \frac{\epsilon'_{cu}}{\epsilon_{cu}} ,$$

the expression for steel strain may be written in the form

$$\epsilon_{su} = \epsilon_{se} + \gamma\, \epsilon_{cu} + \epsilon_{ce} . \tag{10}$$

The use of γ in the compatibility equation changes it from

$$\epsilon_{cu} = \epsilon_u \left(\frac{k_1 k_3}{q_u} - 1 \right)$$

to

$$\epsilon'_{cu} = \gamma\, \epsilon_u \left(\frac{k_1 k_3}{q_u} - 1 \right). \tag{11}$$

Equation (9) can be written as

$$\epsilon_{su} = \epsilon_{se} + \frac{\gamma\, \epsilon_u\, k_1 k_3}{q_u} - \gamma\, \epsilon_u + \epsilon_{ce} \tag{12}$$

and the parameter q_u may be expressed in the following form

$$q_u = \frac{f_{su}\, p}{f'_c} = \frac{\gamma\, \epsilon_u\, k_1 k_3}{\epsilon_{su} - \epsilon_{se} + \gamma\, \epsilon_u - \epsilon_{ce}} \quad . \tag{13}$$

It can be seen from a comparison of Eq. (8) and (13) that the only difference between the expressions for q_u for the bonded and unbonded cases is in the change from ϵ_u to $\gamma\, \epsilon_u$. The coefficient γ depends on the average concrete strain at the level of the steel along the full length of the beam. Since the strain changes from section to section in accordance with the moment, the magnitude of the γ term depends on the type of loading applied to the beam.

For a known coefficient γ and a given stress-strain diagram for the steel, Eq. (13) may be solved by trial.

8. Parameter q_u from Idealized Stress-Strain Diagram of Wire.

It is convenient to be able to solve for the ultimate steel stress parameter q_u directly. This can be done by assuming an idealized stress-strain curve for the steel having two distinct slopes E_s and αE_s as shown in Fig. A3. Two expressions can then be written for the ultimate steel stress for the bonded or unbonded case depending on whether the ultimate stress is less than or greater than the idealized "yield point", f_{sy}. It should be pointed out that the cold drawn wire reinforcement selected for the experimental studies described in Section B of this progress report does not have a definite yield point, but its stress-strain curve can be approximated fairly well by two straight lines with f_{sy} being the break point.

(a) Bonded case, over-reinforced beam, ($f_{su} < f_{sy}$). Consider

first the bonded case with the steel stress at ultimate less than the idealized proportional limit. For this case $f_{su} = E_s \epsilon_{su}$. Both sides of Eq. (7) can be multiplied by E_s to obtain

$$f_{su} = f_{se} + \frac{k_1 k_3 \epsilon_u E_s}{f_{su}\, p/f'_c} - E_s \epsilon_u + E_s \epsilon_{ce}. \tag{14}$$

It is convenient to change this into a dimensionless form by multiplying through by p/f'_c, and to define the various parameters as follows:

$$q_e = \frac{f_{se}\, p}{f'_c}$$

$$Q = \frac{E_s\, p}{f'_c} \quad .$$

Equation (14) then becomes

$$q_u = q_e + \frac{k_1 k_3 \epsilon_u Q}{q_u} - Q \epsilon_u + Q \epsilon_{ce}$$

or

$$q_u^2 = q_u (q_e - Q \epsilon_u + Q \epsilon_{ce}) + k_1 k_3 \epsilon_u Q.$$

Solving this quadratic for q_u

$$q_u = \frac{1}{2} (q_e - Q \epsilon_u + Q \epsilon_{ce}) + \sqrt{\frac{1}{4} (q_e - Q \epsilon_u + Q \epsilon_{ce})^2 + k_1 k_3 Q \epsilon_u} \, . \tag{15}$$

Equation (15) may be simplified, generally without serious error, to the following form since the ϵ_{ce} term usually is quite small compared to q_e or ϵ_u :

$$q_u = \frac{q_e}{2} \; \frac{-Q \epsilon_u}{2} + \sqrt{k_1 k_3 Q \epsilon_u} \, . \tag{16}$$

If the prestress is zero, q_e and ϵ_{ce} are zero, and Eq. (15) reduces to a form so that the ultimate moment given by Eq. (4) is the same as for ordinary reinforced concrete beams.

(b) <u>Bonded case, under reinforced beam ($f_{su} > f_{sy}$)</u>. If the inelastic portion of the stress-strain curve can be represented by a straight

line having a slope of αE_s as shown in Fig. A3, the following expression can be written for the ultimate steel strain.

$$\epsilon_{su} = \epsilon_y + \frac{f_{su} - f_{sy}}{\alpha E_s} \tag{17}$$

In this expression ϵ_y is the strain corresponding to a steel stress f_{sy} as shown in Fig. A3. Insertion of this value for ϵ_{su} in Eq. (7) and multiplication of both sides of Eq. (7) by E_s yields

$$f_{sy} + \frac{f_{su} - f_{sy}}{\alpha} = f_{se} + \frac{k_1 k_3 \epsilon_u E_s}{q_u} - E_s \epsilon_u + E_s \epsilon_{ce} \tag{18}$$

Introduction of the parameters gives

$$q_u - q_y = \alpha \left(q_e - q_y + \frac{k_1 k_3 \epsilon_u Q}{q_u} - Q \epsilon_u + Q \epsilon_{ce}\right)$$

where

$$q_y = \frac{f_{sy} p}{f'_c} .$$

This may be solved for q_u:

$$q_u = \frac{1}{2}\left[q_y + \alpha(q_e - q_y - Q \epsilon_u + Q \epsilon_{ce})\right] + \sqrt{\frac{1}{4}\left[q_y + \alpha(q_e - q_y - Q \epsilon_u + Q \epsilon_{ce})\right]^2 + \alpha k_1 k_3 Q \epsilon_u} \tag{19}$$

(c) Unbonded case, over reinforced beam ($f_{su} < f_{sy}$). The unbonded case solutions are very similar to those for the corresponding bonded case. One difference is that an assumption for γ is required. The expressions for q_u are:

$$q_u = \frac{1}{2}(q_e - Q \gamma \epsilon_u + Q \epsilon_{ce}) + \sqrt{\frac{1}{4}(q_e - Q \gamma \epsilon_u + Q \epsilon_{ce})^2 + \gamma k_1 k_3 Q \epsilon_u} . \tag{20}$$

Or, making some simplifying assumptions,

$$q_u = \frac{q_e}{2} - \frac{Q \gamma \epsilon_u}{2} + \sqrt{k_1 k_3 Q \gamma \epsilon_u} . \tag{21}$$

(d) Unbonded case, under reinforced beam ($f_{su} > f_{sy}$). The unbonded case solution for q_u when the ultimate steel stress is in the inelastic range is similar to the expression given by Eq. (19) for the bonded case. As before the only effect is to change ϵ_u to $\gamma\ \epsilon_u$ for the unbonded case. The equation is

$$q_u = \frac{1}{2}\left[q_y + \alpha\ (q_e - q_y - Q\ \gamma\ \epsilon_u + Q\ \epsilon_{ce})\right] + \sqrt{\frac{1}{4}\left[q_y + \alpha\ (q_e - q_y - Q\ \gamma\ \epsilon_u + Q\ \epsilon_{ce})\right]^2 + \alpha\ k_1 k_3\ Q\ \gamma\ \epsilon_u}\ . \qquad (22)$$

9. Comparison of Ultimate Moment Capacities Based on Actual and Idealized Stress-Strain Diagrams for the Wire.

The ultimate moment capacity can be computed by using Eq. (4). Two methods of computing the term q_u which appears in this equation have been given for both bonded and unbonded beams. Each method has its advantages and disadvantages.

The first method which involves use of the actual curve is the most accurate, particularly at ultimate steel strains greater than about 5 percent as can be seen from Fig. A3; however, it requires a trial and error solution. If only a few beams are to be analyzed, it probably is the quickest and easiest method of finding the parameter q_u. However, the idealized solutions are the easiest to use when studying the effect of varying any particular term.

Since the parameter q_c is equal to $\frac{Q\ f_{se}}{E_s}$ and the parameter q_y equal to $\frac{Q\ f_{sy}}{E_s}$ the equations for q_u (Eq. 15, 16, 19, 20, 21, or 22) can be expressed in terms of Q, f_{se}, ϵ_u, γ, k_1k_3, ϵ_{ce}, and the stress-strain properties of the steel reinforcement. One of the major variables in

the idealized case expressions for q_u is seen to be Q which is equal to $\frac{E_s\, p}{f'_c}$. For a particular beam, Q can be evaluated. Hence plots of $\frac{M_{ult}}{f'_c bd^2}$ versus $Q = \frac{E_s p}{f'_c}$ have been used. If the other quantities are either known or assumed, Q determines the magnitude of $\frac{M_{ult}}{f'_c bd^2}$ and whether the beams are over or under-reinforced.

Figure A4 has been constructed by using Eq. (4), (8), (15), (16), and (19). The continuous dashed curve was obtained by using Eq. (4) and (8), and the actual stress-strain curve of the wire. By assuming the concrete elastic at effective prestress, a value for $\frac{f_c}{E_c}$, and a value for d/h, the quantity ϵ_{ce} can be expressed in terms of the prestress parameter q_e which in turn is a function of Q. This was done for the idealized case solutions as well as for the actual stress-strain curve solution. Equation (19) was used to construct the portion of the idealized curve below the break point in Fig. A4.

The so called "exact" expression (Eq. 15) and the simplified expression (Eq. 16) were used to construct the two idealized curves for the portion above the break point as shown in Fig. A4. The simplified case solution is in fair agreement with the actual stress-strain curve solution. Hence, because of its simplicity, Eq. (16) has been used in later plots to study the effects of other variables. As might be expected the greatest deviation between the "exact" idealized curve and the actual stress-strain curve occurs near the break point of the idealized curve. The quantities required to construct Fig. A4 are given on the figure.

The agreement is not as good for the unbonded case for which similar comparisons are given in Fig. A5. The trial process computations

have shown that for a variation of Q from 10 to 90 the steel strain varied from 0.016 to 0.006. This range represents only a small portion of the steel stress-strain curve involving the break point (Fig. A3) and explains the rather large differences between the idealized expressions and the actual curve for M_{ult} versus Q. Here the approximate form is considerably in error, particularly at high values of Q. The "exact" and "approximate" idealized equations used are indicated on the figure.

It should be emphasized that the curves given are for a particular wire with a particular stress-strain relationship. If this relationship cannot be represented adequately by two straight lines the idealized expressions are not valid.

III. EFFECT OF VARIABLES

The primary quantities appearing in the equations for ultimate moment are: the percentage of steel, the effective tensioning stress in the steel (f_{se}), the modulus of elasticity of the steel, and the compressive strength of the concrete (f_c'). In addition, certain parameters relating to the shape and magnitude of the compressive stress block appear in the analysis, as well as the stress-strain properties of the steel reinforcement.

The factors listed below have been varied to study their effects on the ultimate moment versus $Q = \frac{E_s p}{f_c'}$ curves.

Bonded Beams:

(1) Effective tensioning stress in steel, f_{se}.

(2) k_2

(3) $k_1 k_3$

(4) ϵ_u

Unbonded Beams:

(1) Effective tensioning stress in steel, f_{se}.

(2) The ratio γ, of the average concrete strain to the maximum concrete strain at the level of the steel.

10. Effect of Prestress in Bonded Case

The effect of the prestressing force has been considered in Fig. A6. The two distinct portions of any one curve result from assuming the idealized stress-strain curve of the wire; the break points correspond to f_{sy} of Fig. A3. Points for individual curves were computed from Eq (16) and (19). A smooth curve results if an actual steel stress-strain curve is used.

In all of the figures, the portion below the break points represents a failure by crushing while the steel stress is above the "yield" value, f_{sy}. It can be seen that the amount of prestress has little effect on the ultimate moment for this type of failure. This is to be expected for under-reinforced beams. However, deflections would not be the same in a given beam for the different amounts of prestress.

The so called "compression" failures are those in which the ultimate steel stress is below the idealized yield point when the concrete crushes (over-reinforced beams). For this case the amount of prestress has a considerable effect on the ultimate moment capacity. The effect of prestress is to shift the entire "compression" curve up, thus changing the idealized break point also.

11. Effect of Prestress for Unbonded Case

Figure A7 contains curves for beams with unbonded reinforcement for three different values of prestress, f_{se}. As for beams with bonded reinforcement the effect of the magnitude of prestress on the ultimate moment is neglible for under-reinforced beams, but is important for over-reinforced beams. Furthermore the range of under-reinforced beams depends on the prestress in a manner similar to that for bonded beams.

It can be seen from a comparison of corresponding curves in Fig. A6 and A7, that the range of under-reinforced beams with unbonded reinforcement is appreciably smaller than for beams with bonded reinforcement. In other words, the unbonded beams have a larger range of "compression" failures. For the unbonded case, the ultimate steel strain is always less than the corresponding bonded case ultimate steel strain because of the γ factor.

12. Effect of Parameter k_2

This parameter defines the location of the resultant compressive force resisted by the concrete (Fig. A1). The magnitude of the parameter k_2 depends on the shape of the stress block, being 1/3 for a triangular distribution and 1/2 for a rectangular distribution of stress. For purposes of this study values of k_2 = 0.40, 0.45 and 0.50 were chosen.

In Fig. A8 curves are plotted for three values of k_2 for bonded beams. It can be seen that the ultimate moment is not very sensitive to variations of the parameter k_2. In the studies of other variables a value of k_2 = 0.4 was used.

13. Effect of the Parameter k_1k_3

The parameter k_1 is the ratio of the average compressive stress to the maximum compressive stress, and the parameter k_3 is the ratio of the compressive strength of concrete in flexure, f_c'', to the cylinder strength, f_c'. Both of these parameters affect the magnitude of the compressive force C (Fig. A1). The parameters k_1 and k_3 appear in all expressions only as the product k_1k_3, but to aid in evaluation of the parameters they have been kept separate in all equations.

The parameter k_1 for the triangular stress block is equal to 0.5, for the rectangular stress block it is equal to 1.0. In studies pertaining to ordinary reinforced concrete beams the parameter k_3 is usually taken as 0.85 to 1.00. This gives a range in k_1k_3 of 0.425 to 1.00. For the purposes of this study values of k_1k_3 = 0.50, 0.75, and 1.00 were chosen.

In Fig. A9 curves are plotted for bonded beams for these three values of k_1k_3. It can be seen that for over-reinforced beams the

ultimate moment M_{ult} is very sensitive to k_1k_3. For studies of other variables k_1k_3 was chosen as 0.75.

14. Magnitude of Ultimate Strain ϵ_u

The analysis presented in Chapter II is based on the assumption that the ultimate moment is reached when the concrete crushes at a limiting concrete strain. Various investigators found that for ordinary reinforced concrete the ultimate flexural strain for concrete in compression is about 0.0040.

In Fig. A10 curves are shown for bonded beams for ϵ_u varying from 0.0026 to 0.0044. It can be seen that the ultimate moment for under-reinforced beams is not affected by the choice of ϵ_u and that the effect of ϵ_u on the capacity of over-reinforced beams is not great.

For other studies a value for ϵ_u of 0.0038 was used.

15. Effect of Ratio of Average Concrete Strain to the Maximum at the Steel Level, γ

It has been shown in Section 7 that the conditions of compatibility for beams with unbonded reinforcement can be satisfied by introducing the coefficient γ. If an unbonded beam is subjected to a constant moment throughout its length then $\epsilon'_{cu} = \epsilon_{cu}$, and $\gamma = 1$. Hence the expressions for the unbonded case reduce to those for a bonded case. For beams with unbonded reinforcement, not under pure moment, γ is less than 1, and its magnitude depends on the type of loading. Some theoretical studies have indicated that for third-point loading $\gamma = 1/3$ for beams with straight reinforcement.

In Fig. A11 curves are plotted for three values of γ. The curves

were computed by use of Eq. (13) and the actual stress-strain diagram of the steel.

IV. LIMITS BETWEEN VARIOUS MODES OF FAILURE

16. Beams with Simultaneous Crushing of Concrete and Yielding of Reinforcement

Since the actual stress-strain diagram for cold drawn wire reinforcement does not have a well defined yield point there is no well defined limit between over and under-reinforced beams. If, however, a certain steel strain is taken as the yield strain, the critical q_y giving the limits between the two types of beams may be computed from Eq. (8) and (13) for bonded and unbonded beams respectively.

17. Beams with Simultaneous Crushing of Concrete and Fracture of Reinforcement

If at the maximum load the strain in the steel reaches its ultimate value, the reinforcement will fracture simultaneously with crushing of the concrete. The critical q_u may be computed from Eq. (8) or (13) by substituting the value of ultimate steel strain ϵ_s' for ϵ_{su}.

It should be pointed out, however, that the ϵ_s' to be substituted into Eq. (8) is not necessarily the same as that found from a tension test of wire. Equation (8) is based on the assumption of perfect bond, and although the overall bond condition may justify this assumption, it certainly does not represent the actual conditions. At a crack the bond will be broken for some distance away from the crack. Therefore, there will be some local variations of steel strains from point to point along the beam, and the theory is incapable of predicting these local variations.

18. Fracture of the Steel at the Load Corresponding to First Cracking

If the ultimate tensile load carrying capacity of the steel is

smaller than that of the concrete before cracking, first cracking of the concrete will be followed by rupture of the steel without any increase in the load.

Such a condition may occur if the percentage of steel is very low. This critical percentage may be computed by assuming an elastic analysis to be valid.

V. CONCLUSIONS

The analysis and the studies of the effects of several variables and parameters entering the analysis have been used in the planning of the experimental program of the investigation. In the future, the analysis may be used for more extensive studies of the effects of significant variables. However, before this can be done, parameters entering the analysis must be determined and the validity of the assumptions substantiated by tests of beams.

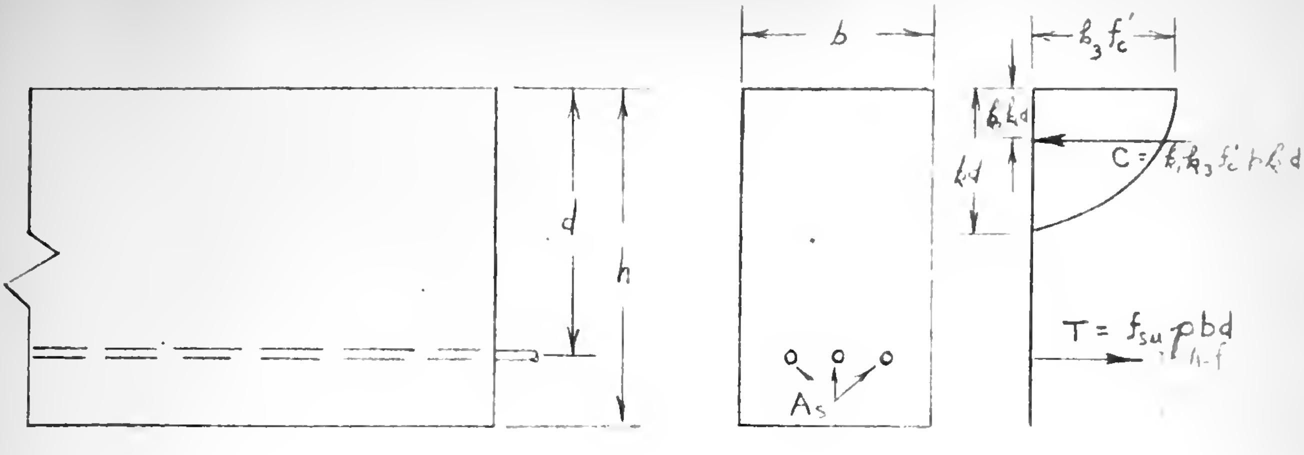

FIG. A1

STRESS CONDITION AT ULTIMATE

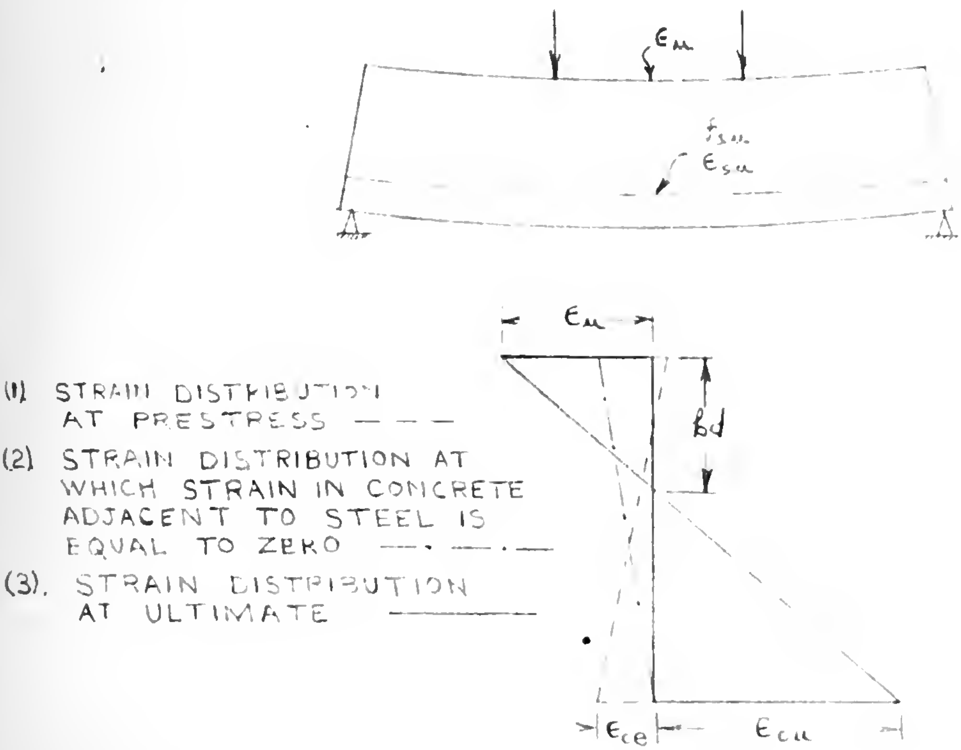

FIG. A2

STRAIN DISTRIBUTION IN CONCRETE

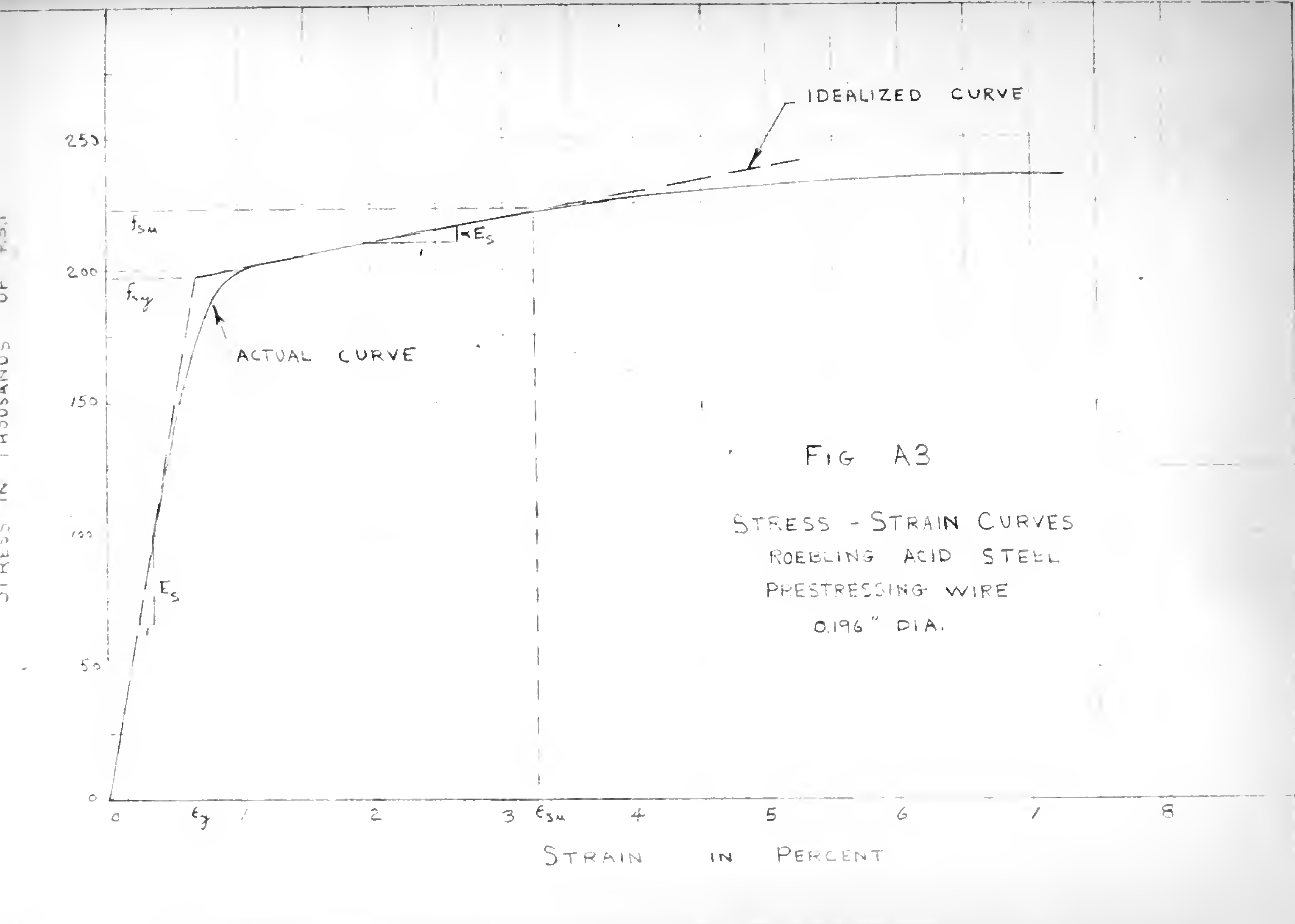

FIG A3

STRESS - STRAIN CURVES
ROEBLING ACID STEEL
PRESTRESSING WIRE
0.196" DIA.

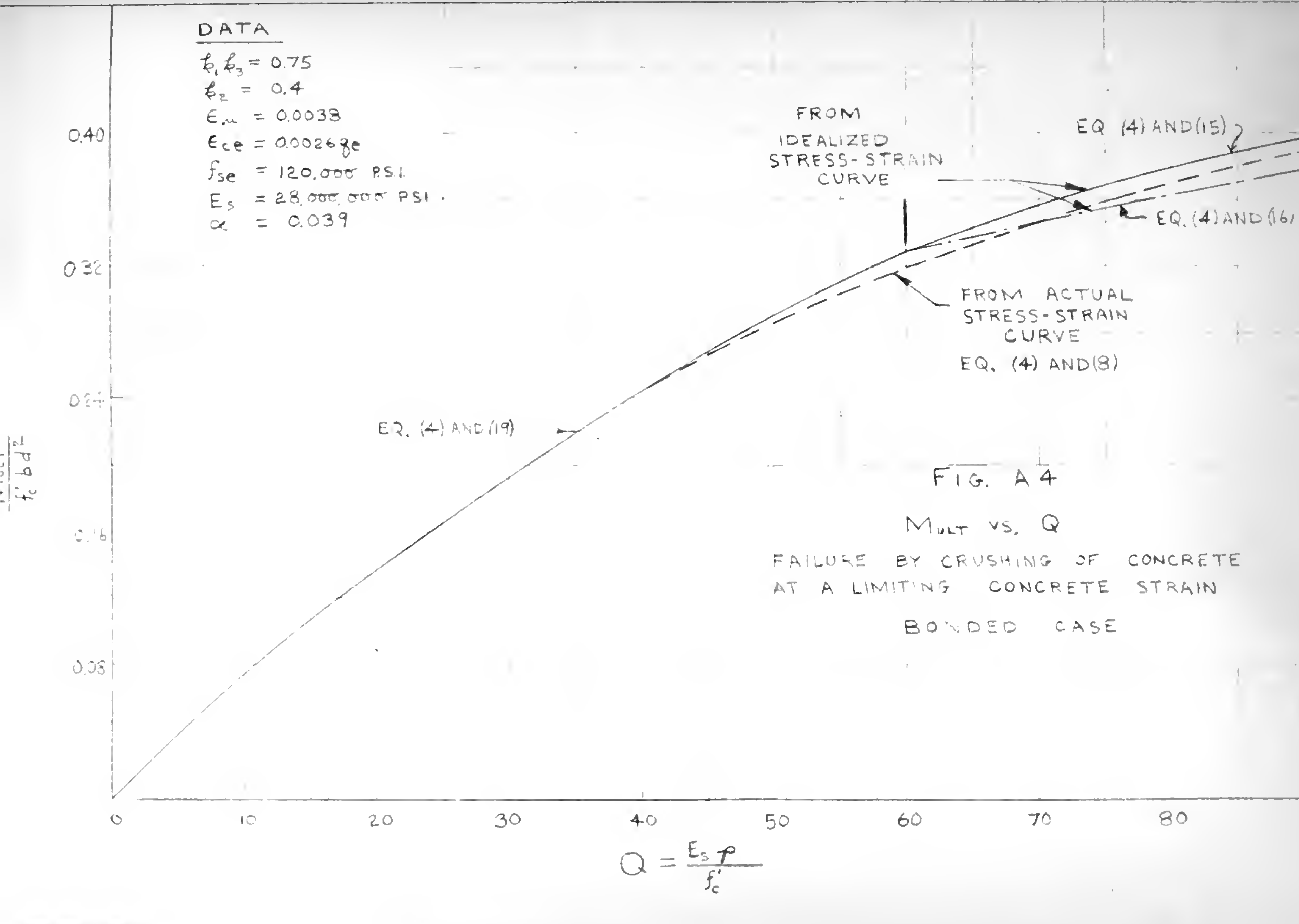

FIG. A 4

M_{ULT} VS. Q

FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN

BONDED CASE

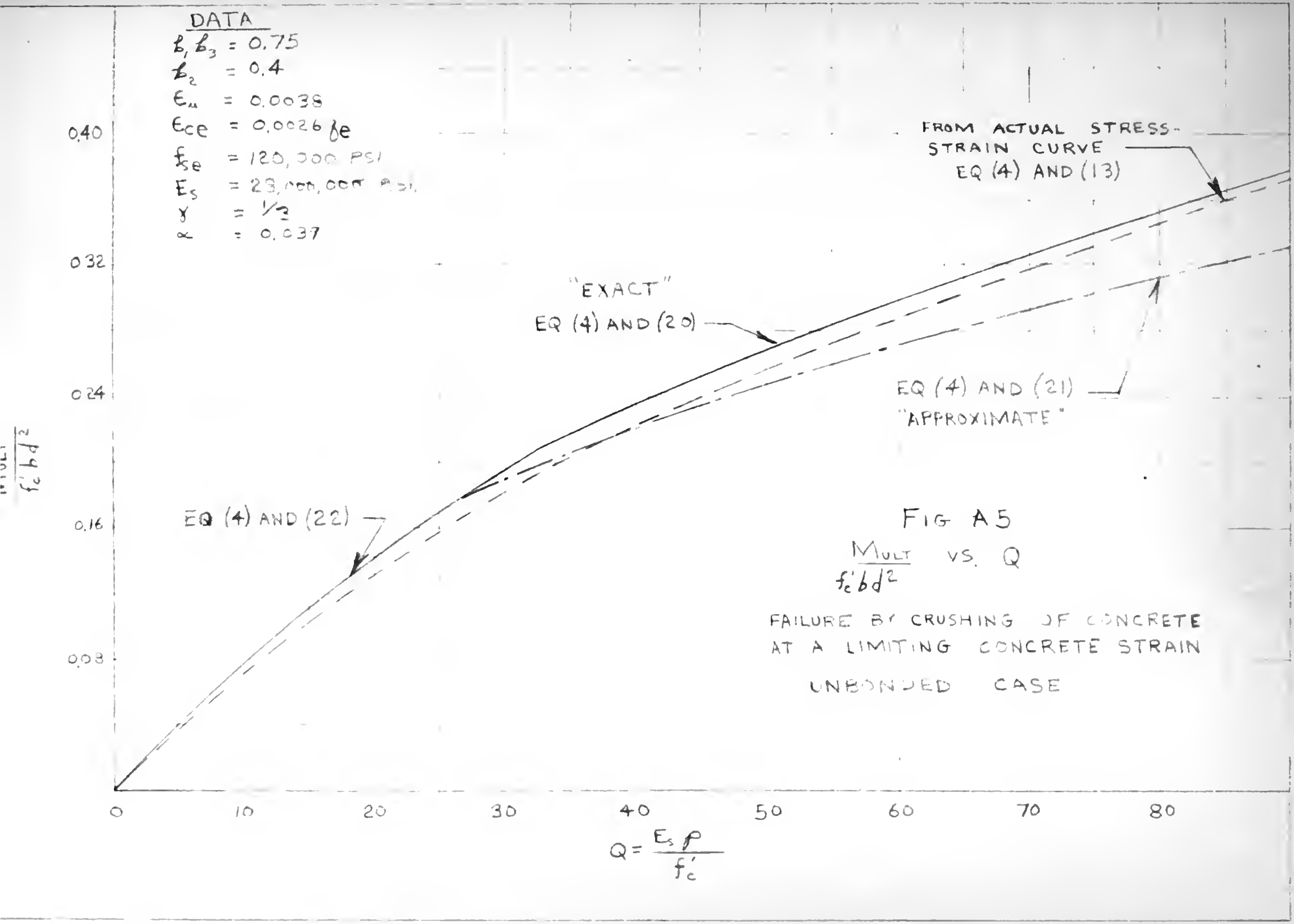

FIG A5

$\frac{M_{ULT}}{f'_c b d^2}$ VS. Q

FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN

UNBONDED CASE

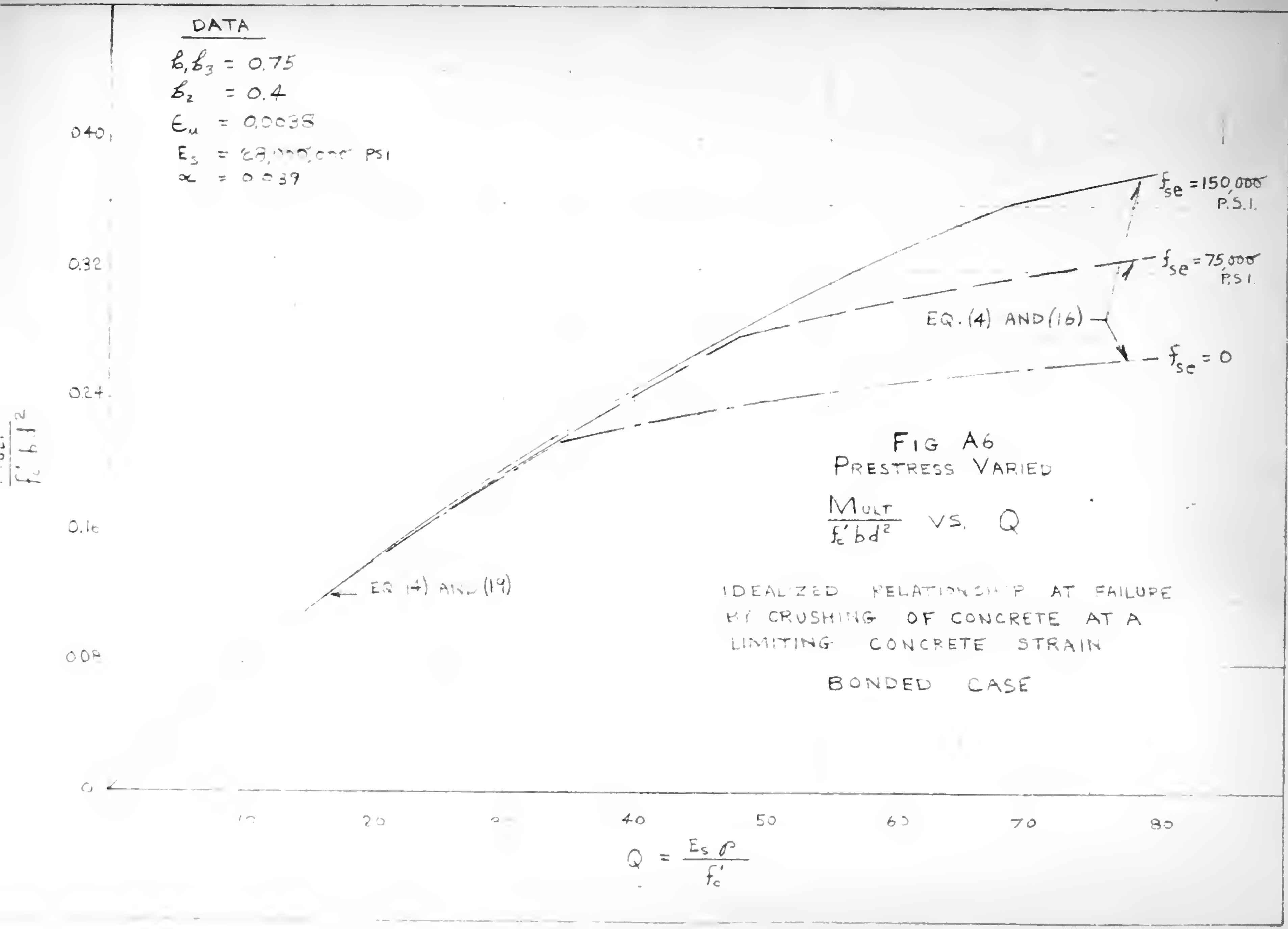

FIG A6
PRESTRESS VARIED

$\frac{M_{ULT}}{f'_c b d^2}$ VS. Q

IDEALIZED RELATIONSHIP AT FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN

BONDED CASE

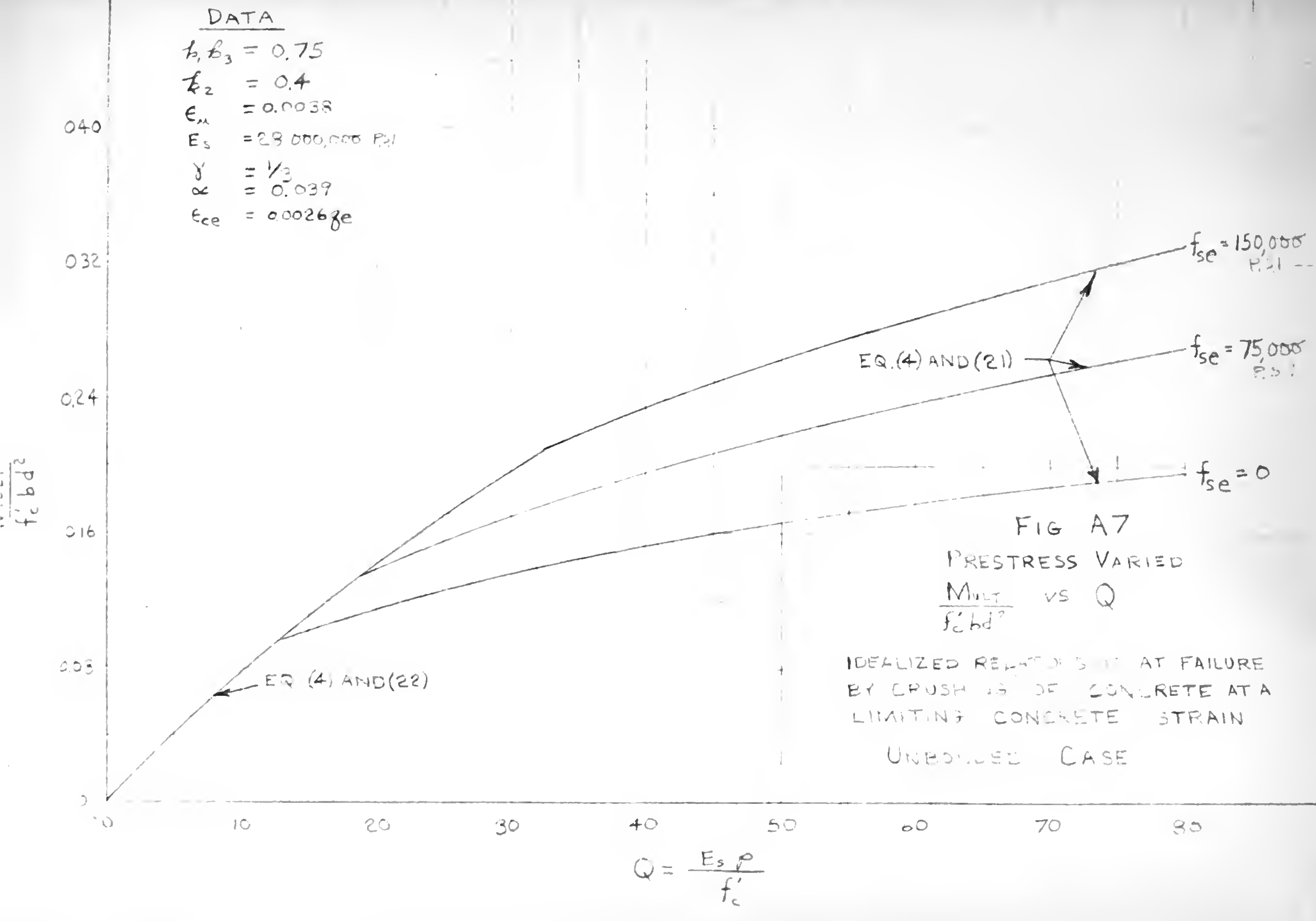

FIG A7
PRESTRESS VARIED
$\frac{M_{ULT}}{f'_c bd^2}$ VS Q
IDEALIZED RELATIONSHIP AT FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN
UNBONDED CASE

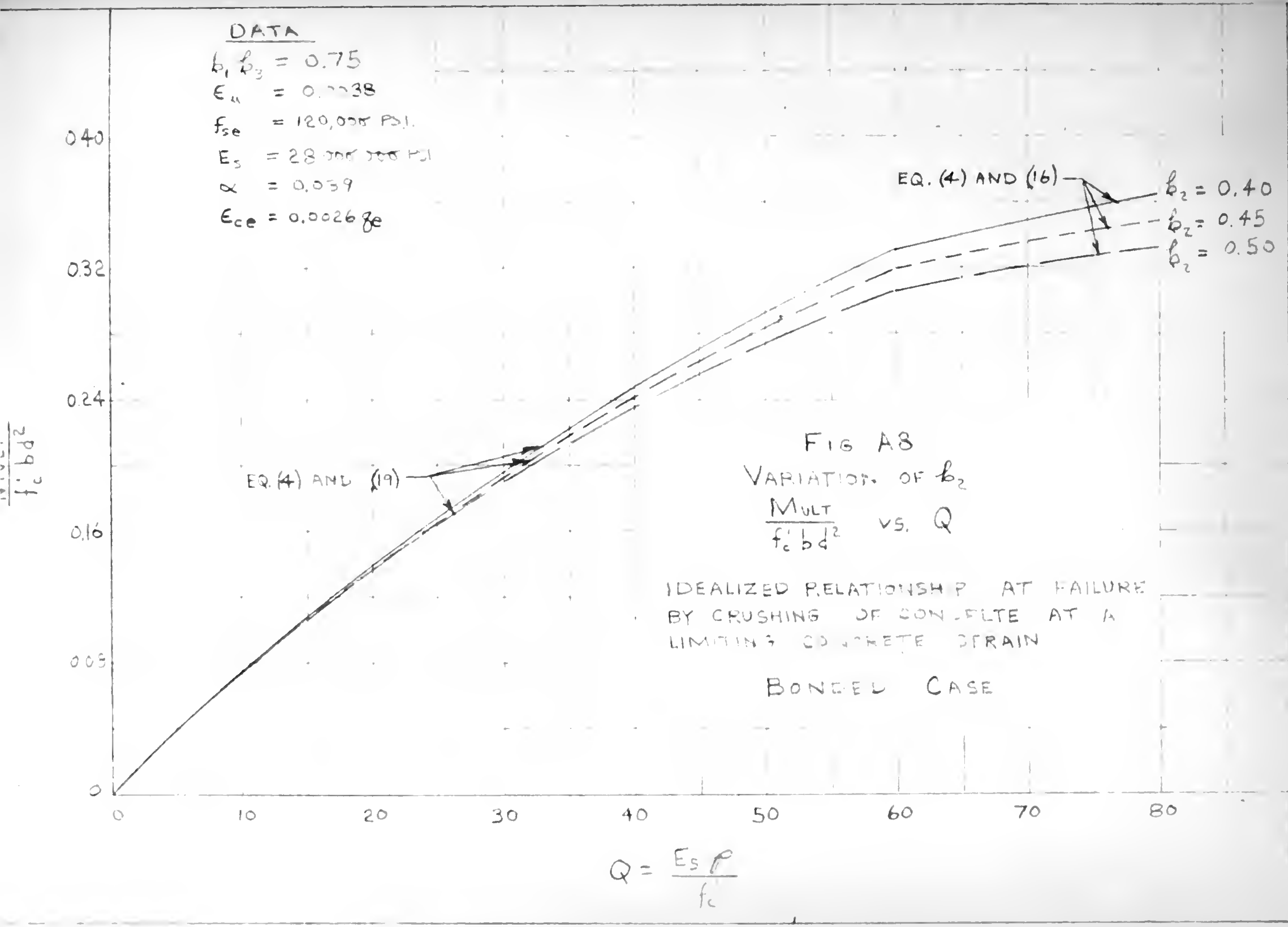

FIG A8
VARIATION OF k_2
$\frac{M_{ULT}}{f'_c bd^2}$ VS. Q

IDEALIZED RELATIONSHIP AT FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN

BONDED CASE

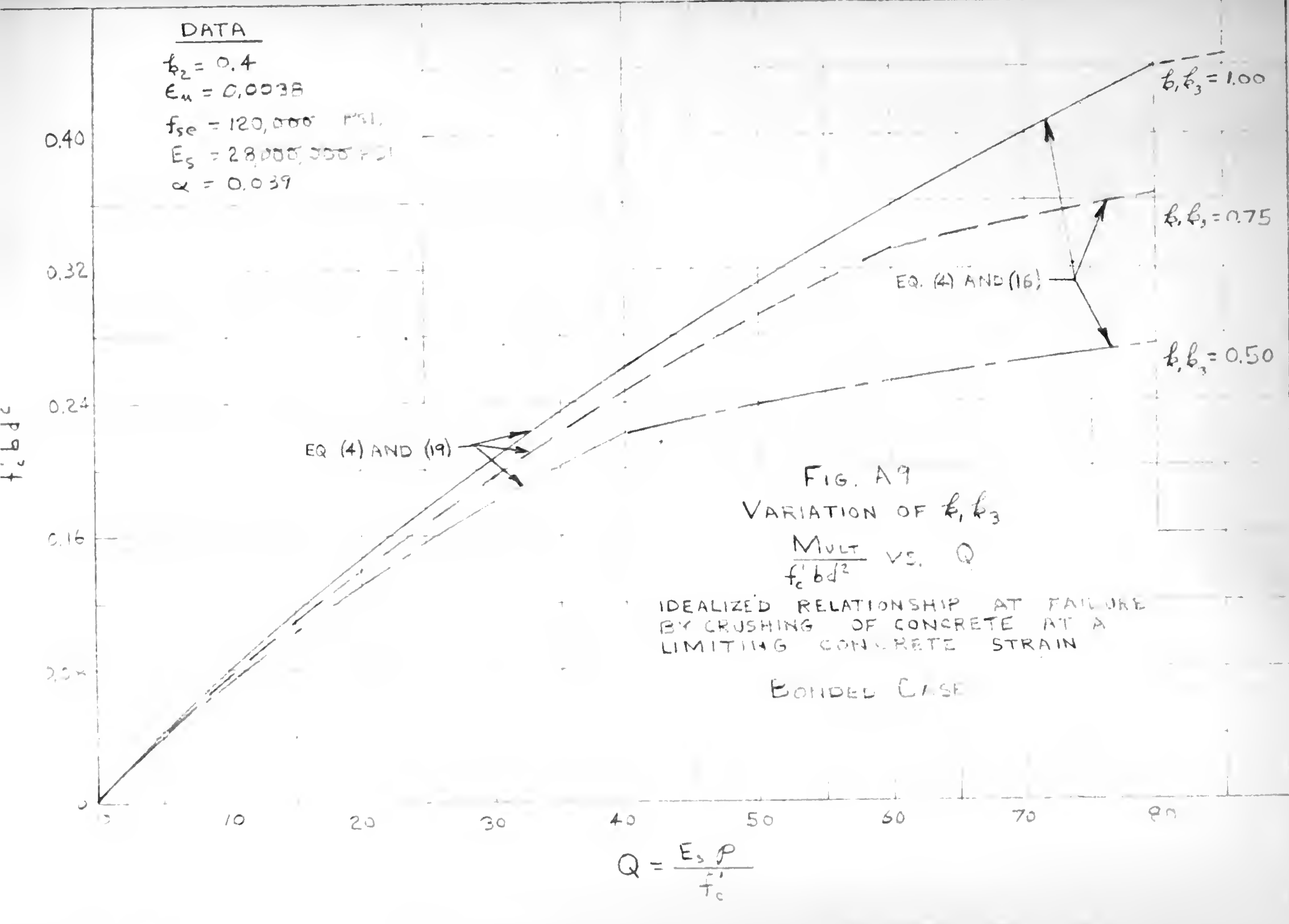

FIG. A9
VARIATION OF $k_1 k_3$
$\frac{M_{ULT}}{f'_c b d^2}$ VS. Q
IDEALIZED RELATIONSHIP AT FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN
BONDED CASE

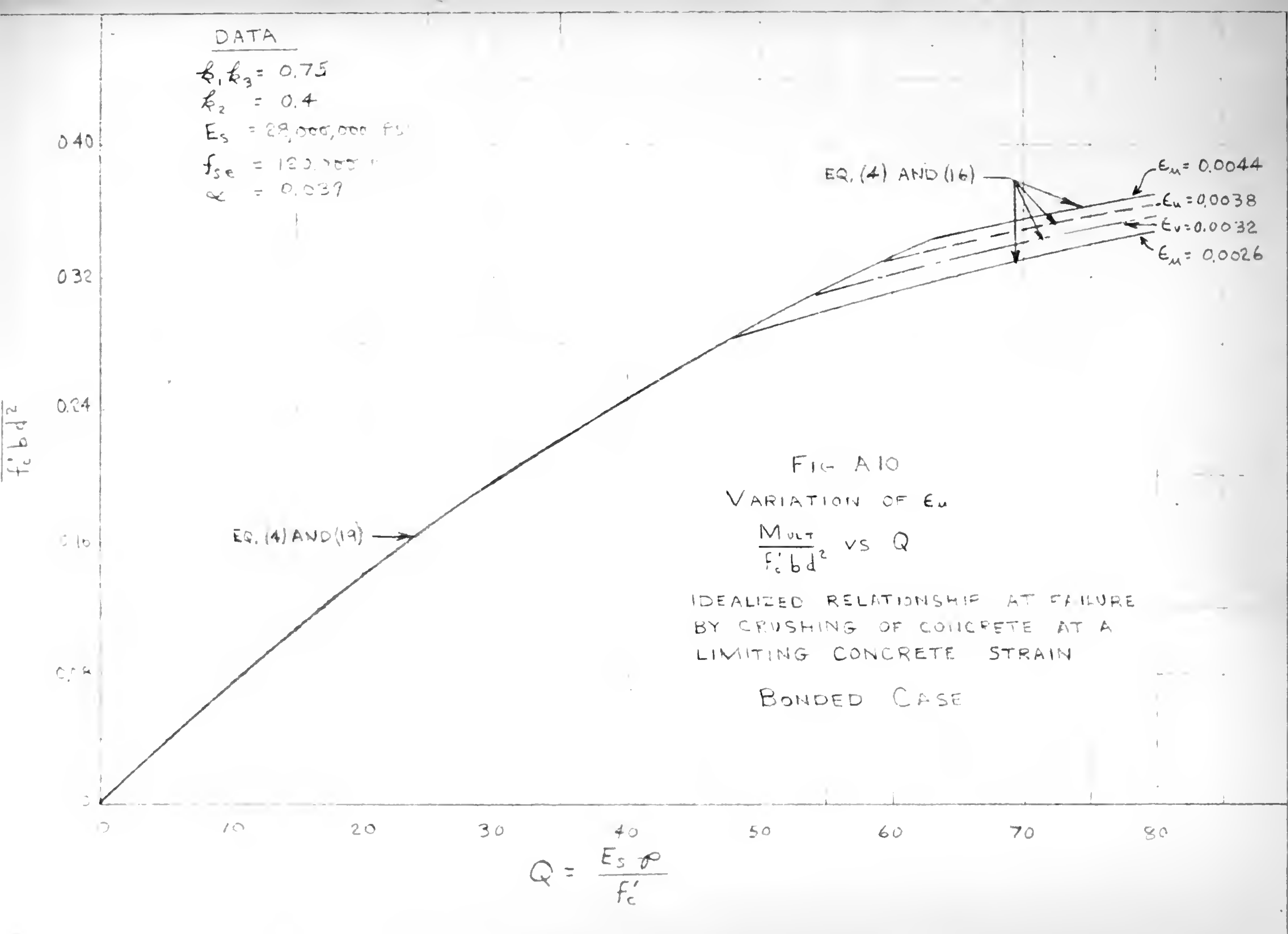

FIG. A10

VARIATION OF ϵ_u

$\frac{M_{ult}}{f'_c b d^2}$ VS Q

IDEALIZED RELATIONSHIP AT FAILURE BY CRUSHING OF CONCRETE AT A LIMITING CONCRETE STRAIN

BONDED CASE

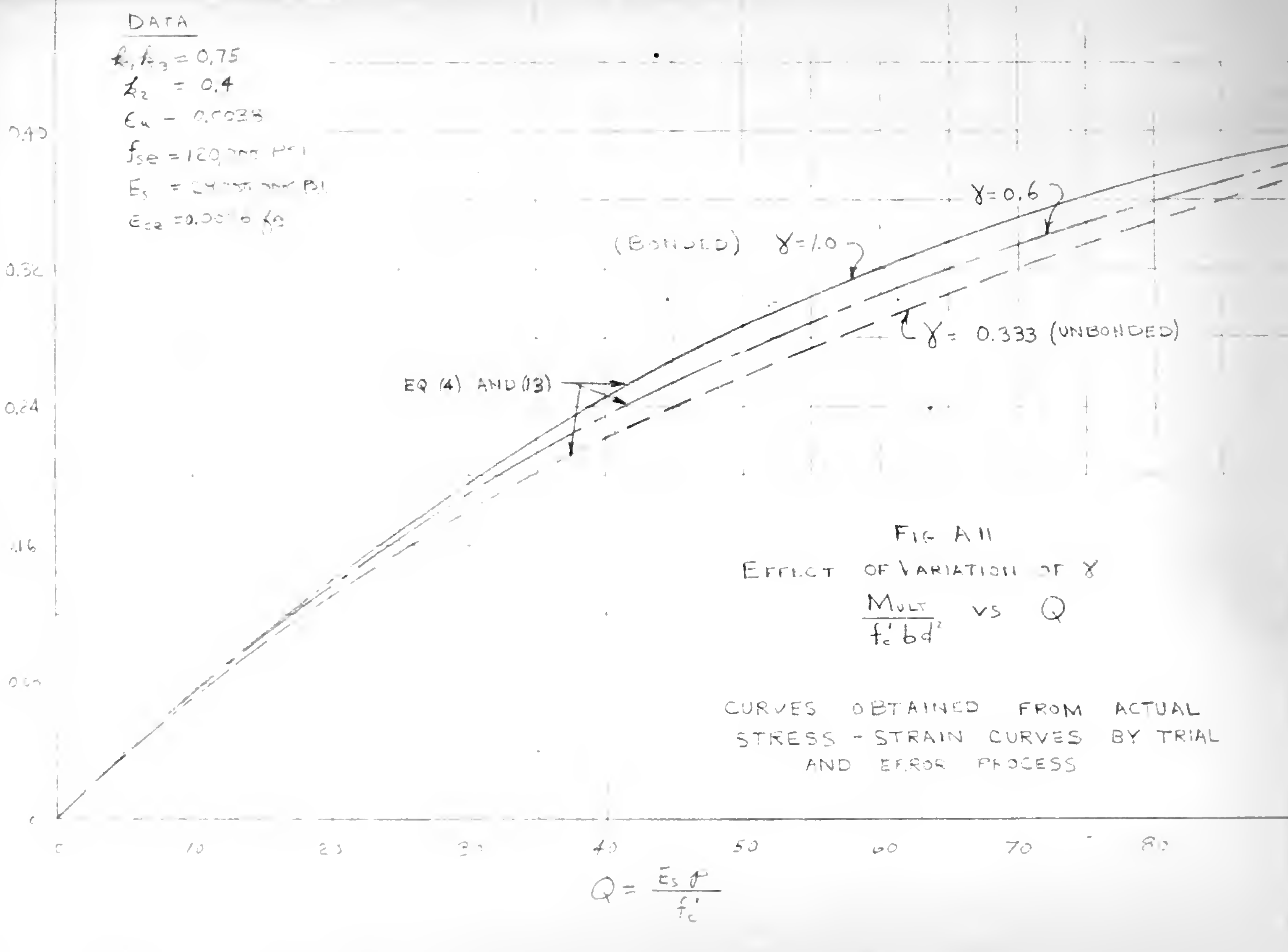

FIG A11
EFFECT OF VARIATION OF γ
$\frac{M_{ULT}}{f'_c b d^2}$ VS Q

CURVES OBTAINED FROM ACTUAL STRESS - STRAIN CURVES BY TRIAL AND ERROR PROCESS

SECTION B

PROGRESS REPORT

ON TESTS OF PRESTRESSED CONCRETE BEAMS

by

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April, 1952

CONTENTS

TESTS OF PRESTRESSED CONCRETE BEAMS

I. INTRODUCTION

1. Object of Tests

The primary object of the first series of tests of this investigation is the study of the flexural behavior of post-tensioned, end-anchored, bonded beams. In this type of prestressed concrete construction, the reinforcement is tensioned and anchored after the concrete has hardened and bond is established between the concrete and steel by surrounding the reinforcement with a sand-cement grout. The second and equally important objective of the tests is the determination of the adequacy and validity of the analytical method of computing the flexural strength of prestressed concrete beams reported in Section A. The beam tests and a number of allied tests are being conducted simultaneously to determine the adequacy of equipment for tensioning and anchoring the reinforcement of the beams.

Post-tensioned, bonded beams are well suited for test specimens. Since the prestressing force may be controlled closely, the factors involved in the analysis in Section A are most readily evaluated in beams of this type.

2. Scope of Report

A major part of this report is devoted to a description of the development of equipment and techniques used in the construction and prestressing of the beam specimens. Another part is devoted to numerous auxiliary tests made in connection with the development of equipment for prestressing and testing the beams. Tests of three beams are reported. These beams were exploratory specimens in that they were intended

primarily to test the adequacy of the equipment and techniques.

A description of the specimens and the equipment and procedures used to establish bond between the reinforcement and beam is presented in Chapter II. The details of the equipment used in loading the beams are presented in Chapter II.

The operation of tensioning and anchoring the highly stressed reinforcement presented a major problem in the construction of the prestressed concrete beams. Since the equipment and techniques now used in the field are not too well suited for laboratory specimens, much of the work done during the past year has been devoted to the development of equipment for prestressing as reported in Chapter III.

A number of auxiliary tests were required before the beam tests could be started. They include: (1) Trial batches of concrete for the beams. (2) Tests of anchorages of the wire reinforcement. (3) Tests to determine the properties of the reinforcement. (4) A few pull-out bond tests to determine the bond characteristics of the wire reinforcement. The results of these auxiliary tests are reported in Chapter IV.

Preliminary results of the tests on three post-tensioned bonded beams are reported in Chapter V. These beams are the exploratory specimens of a series in which the percentage of steel is the major variable. The beams were tested on a 9-ft span with loads applied at each third point. Measurements were made of strains in the concrete and steel and of deflections.

II. DESCRIPTION OF SPECIMENS

3. Description of Beams

The three beams tested were rectangular, post-tensioned, bonded beams, designated B1, B2, and B3. The numbers denote the order in which they were tested. The beams consisted of a rectangular concrete section, high-strength steel wire reinforcement, and end bearing plates used to transfer the prestressing force from the wires to the beam. The wire reinforcement extended in a straight line between the bearing plates at each end of the beam. The beams had no reinforcement other than the high-strength steel wires.

The beams were nominally 6 by 12 in. in cross section and 10 ft in length as shown in Fig. B1. Although the beams were cast in metal forms the dimensions of the beams varied to some extent. The measured widths and heights of the beams are given in Table B1.

The wires used as reinforcement in the beams were centered about 9 in. below the top of the beams. The measured depths to the center of gravity of the steel are given in Table B1 for each beam. The wires were initially stressed to 120,000 psi two days before the beams were tested. Eight 0.196-in. diameter wires arranged in two layers were used in Beam B1; four wires in one layer were used in Beam B2; and two wires in one layer were used in Beam B3. Referring to Fig. B2, the position of the wires was 1-8 for Beam B1, 5-8 for Beam B2, and 6-7 for Beam B3. The wires were spaced on one inch centers. The area, initial tension, and ultimate strength of the steel reinforcement used is listed for each beam in Table B1. The area of steel listed in Table B1 is based upon the measured diameter of the wires. The wires used in Beam B1 were galvanized, and the area given includes that of the galvanizing. The areas of steel

listed for Beams B2 and B3 in Table B1 are based upon the diameter of the wire after the galvanizing was removed, since the galvanizing was removed from the wires in these beams.

A hole, roughly elliptical in cross section, was formed in the lower part of the beam to provide a channel for the reinforcement. The dimensions and position of this hole are shown in Fig. B3. The core form for this hole was composed of eight 1/2-in. steel rods encased in rubber tubing, 13 smaller rubber tubes, and a cover of sheet rubber. The rods were held in position by a steel template at each end of the beam form. The small tubes were placed between and outside of the rods in such a manner that the desired shape of core was formed. A strip of rubber, 4-in. wide, was then wrapped continuously around the tubes. This form was easily removed from the beam by first pulling out the steel rods, and then removing the tubes and rubber winding. The core formed an elliptical hole about 3 1/2 by 2 1/2 in., centered about 9 in. below the top of the beam. This size hole is large enough to provide for the largest percentage of reinforcement anticipated in the current group of beam tests.

4. Materials

The reinforcement of the beams consisted of 0.196 in. diameter strands of Roebling acid-steel prestressing wire. The properties of this wire are described in Section 17. The wires in Beam B1 were used as received; but in order to provide better bond characteristics, the galvanizing on the wires used in Beams B2 and B3 was removed with hydrochloric acid, and the wires rusted in a moist room for 7 days.

In order to provide good distribution of stress from the wires to the ends of the beam, 6-in. by 6-in. by 2-in. thick bearing plates were used. Figure B4 shows the details of the bearing plates.

The concrete in the beams was made of Type I Marquette Portland Cement, Wabash River gravel, and Wabash River torpedo sand. The proportions of the mixes, slump, and various physical properties of hardened concrete are given in Table B2. Sieve analyses of the fine and coarse aggregates are given in Table B4.

The concrete was mixed in a non-tilting drum mixer of 6 cu.-ft capacity and was placed in the forms with the aid of an internal vibrator. Two batches were used in each beams. In spite of the use of a butter mix to condition the mixer prior to mixing the first batch, the strength of two separate batches of the same proportions varied to some extent. In order that the concrete in the constant moment section of the beam be from the same batch, the first batch of each mix was placed in the outer quarter of each beam and the second in the center half.

Beams B1 and B2 were cured under wet burlap for 7 days and stored in the laboratory until tested. Beam B3 was cured in a moist room for 7 days and then stored in the laboratory.

The compressive strengths given in Table B2 represent the average of four 6 by 12-in. cylinders. The moduli of rupture listed in Table B2 were obtained from tests of 6 by 6 by 18-in. control beams. The average initial moduli of elasticity of concrete are also given in Table B2. They were obtained from strains measured on three cylinders from the second batch of Beams B2 and B3. A compressometer having a gage length of 6 in., a multiplication ratio of 2, and a 0.001 in. dial micrometer was used for this purpose.

5. <u>Grouting</u>

Immediately following the tensioning of the reinforcement, grout was pumped into the beam to provide bond between the wires and the

surrounding concrete. The grout was pumped into the beam through a vertical hole located about one foot from the end of the beam as shown in Fig. B3. Pumping was continued until grout was forced out of a similar hole at the other end of the beam.

The grout pump used is shown in Fig. B5. It was constructed of a 5-in. diameter steel tube about 30 in. long and a 1 1/2-ton hydraulic auto bumper jack. A steel plate with a hole threaded for a hose connection was welded to the lower end of the tube. A piston with a cupped pump leather attached was bolted to the base of the bumper jack. The jack was rigidly attached to the cover of the pump in such a manner that the plunger of the jack extended into the cylinder driving the piston. The cover was attached to the cylinder by toggle bolts with wing nuts. This arrangement permitted rapid refilling of the pump. The grout was pumped through a heavy garden hose into the beam. The capacity of the jack was such that a pressure of more than 100 psi could be developed, but the grout flowed freely and the pressure developed in the grout was undoubtedly much less than 100 psi.

The consistency of the grout was that of a thick fluid. Proportions of the mixes used are given in Table B3. The grout was composed of equal parts of Marquette Type III Portland Cement and fine Lake Michigan beach sand. The gradation of the sand is given in Table B4. With grout of such consistency and cement content, a large shrinkage is to be expected. The shrinkage was observed to be quite large in the grout used in Beam B1 and is believed to have contributed to the poor bond characteristics observed during the test of B1. Subsequent bond tests, reported in Section 16, indicated the desirability of eliminating this shrinkage. Accordingly, a small amount of aluminum powder was added to the grout for

Beams B2 and B3. The expansion of the grout caused by the reaction of the cement with the aluminum powder materially improved the bond between the wires and grout. The amount of aluminum added is given in Table B3 in terms of percent of weight of cement.

Four 2 by 4-in. cylinders were cast from the grout mix used in each beam. These cylinders were moist cured until tested. Through an oversight, the grout cylinders for B3 were not tested until four days after the beam test. The cylinders for B1 were tested on the day after the beam test and those for B2 on the day of test. Table B3 gives the compressive strengths of the grout cylinders; each value is the average of four cylinders.

6. Loading Apparatus

The beams were tested on a 9-ft span with loads applied at each one-third point. In order to assure concentric loading and freedom of movement at bearings, the arrangement shown in Fig. B1 was used. The ball and roller combination proved to be stable and provided for the movements that occurred at the bearings during the latter stages of the tests when deflections were large. Beam B1 was tested in a 300,000-lb Olsen screw-type testing machine and the load was measured with the weighing mechanism of the machine. Beams B2 and B3 were tested in a 300,000-lb Riehle screw-type testing machine and the load was measured with a 125,000-lb elastic-ring dynamometer.

III. PRESTRESSING EQUIPMENT AND PROCEDURE

7. End Details of Wires

One of the major problems in the construction and testing of prestressed concrete beams is the development of suitable equipment for tensioning and properly anchoring the highly stressed reinforcement of the beams. In post-tensioned beams, three major classes of anchorages are used in practice: wedge grips, rivet-like heads formed on the ends of the wires, and threaded connections of the ends of the wires.

While wedge grips are reliable and simple, they posses two distinct disadvantages with respect to their use in small test specimens. If the wires are anchored by wedging the wire after tensioning, there is a loss in prestress caused by slipping of the wire on release from the tensioning jack. While this loss may be insignificant in beams of long length, it could result in a considerable drop of stress in short beams, such as test specimens. In addition, the size of wedge grips required is such that it is difficult to obtain the small lateral spacing and grouping of wires desired in test specimens. However, in view of the results of tests reported in Sections 14 and 15, it appears that wedge grips might prove to be the only type of grip capable of developing the ultimate strength of high tensile strength wires.

For beams in which the end anchorage is assisted by bond, as is the case in post-tensioned beams with grouted reinforcement, threaded connections offer a simple means of anchoring the wires, and the wires may be arranged in a compact manner with a relatively small spacing between them. Also there would be practically no loss of prestress when the stress in the wire is transferred from the jack to the bearing plate. Accordingly, some work has been done on the use of threaded wires in

post-tensioned, bonded test beams. The 0.196-in. wire used in the test specimens is rather hard, about Rockwell C-30. The first attempt to thread wires with hand dies was unsuccessful as the wire proved to be so hard that the dies were dulled after cutting only one or two inches of thread. Another attempt was made to thread the wires by use of a threading machine; however, the thread chasers were dulled after cutting a short length of thread. A set of thread chasers with special heat treatment was obtained and used to thread several wires. These chasers were dulled after cutting the threads, but is believed that use of a better technique will eliminate the necessity for frequent resharpening of the chasers, and will allow the use of threaded ends for anchoring the wires. Several tension tests have been made of threaded wires and are discussed in Section 15.

Rivet-like heads, called button heads, were used for anchorages in all beams tested. These button heads, shown in Fig. B6, are relatively simple to form and are capable of developing about 200,000 psi in the wire before failure. About 20 tests of button heads with various types of washers are reported in Section 14.

The button heads are cold formed by use of the apparatus shown in Figs. B7 and B8. To form the head, the wire is placed in a groove between two steel plates and gripped firmly by tightening four 1/2-in. bolts, the wire projecting approximately 7/8 in. above the grip into a housing used to guide a steel plunger. Next a washer, shown in Fig. B9, is slipped over the end of the wire, leaving a projection of about 3/8 in. for formation of the head on the wire. The apparatus is then shimmed on blocks under the compression head of a testing machine. A 5/8 in. round plunger, made of hardened drill rod, with a semi-circular recess in the lower end, is then placed in the housing on top of the grip as shown in

Fig. B8. The head is then formed with pressure from the testing machine. The head formed is about 1/4 in. in diameter with a fillet below the head formed by contact with the chamfer in the washer. Generally, the heads are slightly eccentric because of a tendency of the wire to buckle in the heading operation. However, the heads formed in this manner with proper washers consistently developed from 175,000 to 200,000 psi in the wire. A more complete discussion of the strength of the button heads appears in Section 14.

8. Shimming Device

In conjunction with the button heads, a shimming device was developed to transmit the tensioning force from the washer beneath the button head to the bearing plate on the end of the beam without loss in stress when the jacking force is released. This device, shown in Figs. B4 and B10, consists of a 5/8-in. threaded stud with an internal hole of 0.2-in. diameter, and an internally threaded sleeve 7/8-in. in diameter. In anchoring and tensioning the wire, the wire is passed through the 0.2-in. hole, a washer is slipped over the end of the wire, and a button head is formed. The wire is tensioned by pulling on the 5/8-in. stud. A slotted steel shim, standing next to the 7/8-in. sleeve in Fig. B10, is used to take up large amounts of elongation in the wire. The sleeve is screwed up tight to take up the final amount of shimming. Since the shims fit into the counterbored holes in the bearing plates, shown in Fig. B4, the wires were held in position on 1-in. centers.

9. Tensioning Apparatus

A 10-ton Blackhawk hydraulic ram and pump was used to tension the reinforcement. Figure B11 is a photograph of the apparatus in place

during the prestressing of Beam B3. A jacking frame bolted to the bearing plate provides a reaction for the jack. To tension the wires, the jack reacts against the frame and a yoke. The yoke, composed of two 1-in. steel plates and two 1/2-in. steel rods, transfers the tensioning force from the jack to the wire. Figure B4 shows the connection of the shimming assembly to the yoke accomplished by means of a 5/8-in. bolt and internally threaded sleeve, or union. The jack, reacting against the frame, pushes the yoke outward, tensioning the wire. When the wire is tensioned to the desired stress, the shimming sleeve is turned up tight against the bearing plate, and the pressure in the jack is released.

A jack with a hole through the center of the piston, has been purchased and will be used in future tests to tension the wires. This jack eliminates the necessity of a yoke. Holes will be drilled in the jacking frame corresponding to the position of the wires. Then, a rod running through the jack, jacking frame, and connected to the shimming assembly will transfer the tensioning force from the jack to the wire.

10. Measurement of Tensioning Force

Two means of measuring the tensioning force were used. A pressure gage on the pump operating the jack was used to determine approximately the tensioning force, but the final measurement of the tensioning force was made by use of aluminum dynamometers at the opposite end of the wire. These dynamometers, shown at the top of Fig. B4 and on the right of Fig. B10, were 2-in. lengths of 9/16-in. aluminum rod, with 0.2-in. diameter holes drilled through their centers.

The tensioning force was determined by measuring the compressive strain in the dynamometer by means of two type A7 SR-4 electric strain gages. These gages, attached to opposite sides of the dynamometer, were

wired in series, giving a strain reading which was the average of the strain in the two gages. This arrangement was such that small eccentricities of the load would not affect the strain reading. The dynamometers were calibrated on the 6,000-lb range of a 120,000-lb capacity Baldwin hydraulic testing machine. The calibrations of the dynamometers were so nearly the same that a common load-strain constant could be used for all dynamometers. The strain increment necessary to measure a tensioning stress of 120,000 psi in the 0.196-in. wires was about 1500 millionths. This large increment of strain allowed a fairly precise measurement of stress in the wires, for the strain indicator used had a sensitivity of 2 or 3 millionths.

Figure B4 shows the dynamometer in position. The washer under the button head bears directly on one end of the dynamometer. At the other end, the dynamometer bears on a slotted washer which is counterbored to receive the dynamometer and which in turn fits into a counterbored hole in the bearing plate.

Dynamometers made from 3/4-in. aluminum tubing of 1/16-in. wall thickness were used on Beam B1. However, they were suitable for loads only slightly greater than the prestressing force. These dynamometers proved to be unsuitable under the high wire stresses that developed at the ends of the beam as a result of bond slippage in this beam.

11. Bearing Plates

The bearing plates are shown in Fig. B4. The 6 by 6 by 2-in. plates are heavy enough so that a fairly uniform bearing pressure is realized on the ends of the beam. The heavy bearing plates were used in order to eliminate the need for reinforcement near the ends of the beam and and have proved to be satisfactory in this respect.

12. Tensioning Procedure

Prior to tensioning, a dynamometer was slipped over one end of the wire and a hollow stud over the other. The button heads were then formed on each end. Next the wires were threaded through the bearing plate on which the dynamometers were to bear and all wires pulled through the hole in the beam at the same time. The wires were then threaded through the other bearing plate. After plugging the space around the wires with rubber stoppers to prevent grout leakage, the bearing plates were grouted into place with a thin layer of "Hydrocal" gypsum plaster. After allowing the plaster to harden for about 2 hours, the wires were tensioned individually. The jacking frame was attached to the bearing plate and the yoke connected to the wire and shimming assembly. The jack was placed in position, and each wire in turn was tensioned approximately to the desired value of stress. Then each wire was then retensioned to the desired stress

IV. AUXILIARY TESTS

13. Trial Batches

A series of trial batches was made prior to the beam tests in order to obtain strength-wire and strength-cement-water ratio data for the beam tests. Twelve trial batches, listed in Table B5, were made. The mixes are listed in Table B5 in the order of increasing cement-water ratio and are divided into two groups according to the type of cement. The batches are denoted by a roman numeral and a lower case letter, the numeral denoting the type of cement and the letter distinguishing between mixes made with cement of the same type.

The aggregate was the same as used in the beams. Both Type I and Type III Marquette Portland Cement were used. The batches consisted of mixes large enough for nine 6 by 12-in. cylinders and were mixed in a Lancaster horizontal tub type mixer. The concrete was placed in the cylinders with the aid of an internal vibrator.

The mixes with Type I cement were moist cured for 7 days and stored in the laboratory until tested. Those with Type III cement were moist cured for 3 days and then stored in the laboratory. Three cylinders from each mix were tested at 7, 14, and 28 days for Type I batches and at 1, 3, and 14 days for Type III batches.

Cement-water ratios ranging from 0.80 to 2.94 were used with slumps ranging from 0 to 2 1/2 in. All mixes were plastic except for those with the lowest and highest cement-water ratios. Mixes Ia and IIIa were fairly harsh mixes which exhibited some bleeding and segregation. Mixes If, IIIe, and IIIf were sticky and rubbery because of the high cement content.

In Fig. B12 the cylinder strengths are plotted against the

cement-water ratios at two different ages of test for each type of cement. The data for both cements exhibited a fairly linear relationship between compressive strength and cement-water ratio up to a cement-water ratio of about 2.1 or 2.2. For higher cement-water ratios there is some scatter and very little increase in strength. This indicates that the highest concrete strength obtainable with the aggregate and cements used is about 7,000 psi. A comparison of Fig. B12 with the strengths listed in Table B2 indicates that the strength of batches mixed in the 6 cu-ft mixer is slightly less than those mixed in the Lancaster mixer.

A small quantity of crushed granite is on hand and will be used in additional studies to determine the possibility of obtaining strengths up to 10,000 psi, so that the information will be available if beams with that strength of concrete are desired.

14. Tests of Button Heads

A series of tests have been made on the strength of button heads as anchorages for the highly stressed reinforcement. All tests have been made on specimens of 0.196-in. diameter Roebling prestressing wire. The specimens were about 30 in. long and had a button head and washer on one end.

The variables considered were the type of steel in the washer, the length of washer, and whether there was a fillet on the button head. All washers were made from 1/2-in. round steel rods. These variables are listed in Table B6. The specimens are arranged in groups according to the type of steel from which the washers were made. Within these groups, the specimens are arranged in order of the length of washer used. The designation of the specimen is a number, a letter, another number, and in most cases an F. The first number distinguishes between otherwise similar

specimens. The first letter designates the type of steel in the washer: H for hot rolled, C for cold rolled, B for high strength bolt stock, and D for unhardened drill rod. The second number denotes the length of washer in eighths of an inch. When a letter F is at the end of a specimen designation, there was a fillet under the button head formed by the chamfer in the washer.

All button heads were cold formed using the procedure discussed in Section 7. The specimens were tested in a 120,000-lb capacity Baldwin hydraulic testing machine. One end of the specimen was held in flat face wedge grips. A 1-in. round rod about 4 in. long and with a 0.2-in. hole through its center was held in V-grips to provide bearing for the washer under the button head. All tests were short time tests, the time required being about 5 minutes. Several tests of specimens with defective button heads are not reported. These specimens were those in which the wire buckled during the heading operation and prevented the proper formation of a head.

The results in Table B6 tend to show that the type of material in the washer and the length of washer have little effect upon the strength of the button head. With the exception of 1B4F and 1B2F, all specimens with heads having fillets developed about 200,000 psi before failure occurred. The fillet seemed to help in developing higher strengths. One item not included in Table B6 that should be noted is the fact that the yield strength of the wire, determined at 0.2 percent offset, is about 200,000 psi. Only one specimen developed a strength substantially larger than the yield strength. This specimen, 1C3F, developed a strength of about 95 percent of the ultimate strength of the wire. Three types of failures of button heads are shown in Fig. B6. The lower left hand

specimen had a cup fracture immediately below the head with very little reduction in area. The center specimen on the left in Fig. B6 failed in a similar manner except that there was some tearing of the head. The specimen on the upper right failed, when a small conical section popped out of the top of the head. The washer at the top of Fig. B6 split at the maximum load, the head remaining intact. Two specimens, 1H4F and 2H45, failed when the button head was pulled through the washer. This type of failure occurred only in specimens with washers of hot rolled steel.

These tests are to be continued with the object of obtaining heads that will develop the ultimate strength of the wire.

15. Tests of Wires with Threaded Ends

Tests have been made of wires with threaded ends. As mentioned in Section 7, threads were cut both with hand dies and in a threading machine. The results of tests on the threaded connections are listed in Table B7. Specimens 1 and 2 were threaded with hand dies, and specimens 3, 4, and 5 were threaded with machine dies. The nuts used on specimens 1 and 2 were made from 5/8-in. lengths of 1/2-in. round cold rolled steel rods; on specimens 3, 4, and 5, four machine nuts were used, as shown in Fig. B6. The threads on specimens 1 and 2 were 10-32 threads. Specimens 3, 4, and 5 had 12-24 threads. Since the proper major diameter for 12-24 threads is 0.216 in., the major diameter of the threads on specimens 3, 4, and 5 was 0.020 in. undersize, (0.196 in.). However, short time static tests indicated that the undersized threads developed about 200,000 psi in the wire.

Specimens 1 and 2 failed when the nuts stripped off the wires. It is believed that the low stresses developed were the result of the nuts being drilled oversize. Specimens 3, 4, and 5 failed at stresses of

about 200,000 psi, No. 3 and No. 4 failing by a fracture of the wire in the nuts below the head and No. 5 failing when the threads of the nuts stripped. Specimen 5 was tested after four of eight threaded wires stressed to 120,000 psi in a beam specimen stripped the threads in the nuts over-night, after being tensioned the preceding afternoon. It appears that the undersize 12-24 threads will develop 200,000 psi in the wire in short time tests but will fail by stripping the threads in the machine nuts at stresses as low as 120,000 psi under sustained loading.

These tests will be continued using the 0.196 in. wire with 10-24 full depth threads. In addition, sustained load tests of the threaded connections will be made before threaded wires are used in beams.

16. Bond Tests

As a result of poor bond characteristics obtained with the 0.196 in. galvanized wires used in Beam B1, six pull-out bond tests were made. The properties of the specimens are given in Table B8. The specimens are designated 1, 1A, 2, etc. The letter A denotes an addition of aluminum powder to the mix to counteract shrinkage of the grout. Specimens with the same number were identical except for the addition of the aluminum powder.

In addition to the use of aluminum powder, the surface condition of the wire was varied in the bond tests. The surface conditions were as follows: (1) as received (galvanized), (2) galvanizing removed with hydrochloric acid, and (3) galvanizing removed and the wire rusted in a moist room for three days.

The specimens were 5 3/4-in. cubes cast with the wires horizon-tal. The mix for specimens 1, 1A, 2, and 2A was the same as used in Beam

B1, with the exception of the added aluminum. The mix for specimens 3 and 3A was the same as used in grouting Beam B3. The specimens were moist cured for two days before testing.

All specimens were tested in a 120,000-lb capacity Baldwin hydraulic testing machine. A spherical seat was used under the specimens. Slip was measured at the free end of the wire with a 0.001-in. dial micrometer.

The load-slip curves for the specimens are shown in Fig. B13. The dotted lines in Fig. B13 indicate estimated slip at loads at which slips could not be measured. The hydraulic machine, applying a load rather than a deformation, could not be stopped in time to measure the slips in the regions indicated by the dotted lines. All of the specimens without added aluminum had very poor bond strengths. Specimens 2 and 3, with ungalvanized and rusted surfaces, respectively, were not actually tested. In placing the specimens in the testing machine, it was found that the wires could be moved by hand. They are shown in Fig. B13 as having no bond strength. Specimen 1, with galvanizing, exhibited very little bond strength after first slip at the free end, indicating that the bond was very poor after the adhesion was destroyed. Specimen 1A, with galvanizing, had load-slip characteristics very similar to those of specimen 1, which was an identical specimen but without the added aluminum, but had a bond strength more than twice as great. However, the bond was poor after the adhesion was broken. Specimen 2A, with galvanizing removed, exhibited almost no adhesion but did develop a considerable amount of sliding friction was developed at small slips.

This limited series of bond tests will be continued as any of the following variables are changed in the beam tests: surface condition

of the wire, grout proportions, or size of wire.

17. Tests of Wires

Three sizes of wires have been received in the laboratory. They were all listed by the manufacturer as "Roebling acid steel prestressing wire". The wires are 0.099 in., 0.196 in., and 0.276 in. in diameter. The 0.196-in. wire is galvanized and measures 0.192 in. in diameter after the galvanizing is removed with acid.

A number of specimens of the 0.196-in. wire have been tested. Two specimens of 0.099-in. wire and three of the 0.276-in. wire have been tested. The properties of these wires are listed in Table B9. The values listed for the 0.196-in. and 0.276-in. wires are the averages of two test values, while those listed for the 0.099-in. wire are the values from one test.

The wires were tested in a 120,000-lb capacity Baldwin hydraulic testing machine. Strains in the wire were measured with an 8-in. extensometer and recorded with an automatic recording device. The extensometer employs a Baldwin "microformer" coil in measuring strain. As used, the extensometer had a range of 4 percent strain. In the tests of the 0.196-in. wire, a steel sleeve was used to reduce the gage length to 4 in. and thereby double the strain range. The extensometer is so constructed that it permits strain measurements up to fracture.

Elongations after fracture were measured with a steel rule between scribe marks on the specimens. Elongations measured in a 10-in. gage length including the region of fracture and elongations measured in a similar length outside the region of fracture are given in Table B9. This is done because the elongation outside the fracture plus the strain

recovered upon unloading more nearly represents the ultimate strain which can be developed in a long length of wire.

The stress-strain curves of the three diameters of wire are given in Fig. B14. The curves for the 0.099-in. and 0.276-in. wire represent a continuous stress-strain curve to the range of the extensometer. The curve for the 0.196-in. wire represents a stress-strain curve to fracture; this curve does not include the elongation resulting from the necking of the wire, since the fracture occurred outside the gage length. Hence, the curve shown for the 0.196-in. wire represents the strain that might be expected for a long length of wire.

The specimens of each wire size were from one roll of wire. Specimens from the same roll have almost identical stress-strain curves. The elongations measured after fracture vary to some extent, but most of this variation is probably due to errors in scribing the gage marks on the specimens rather than to variations from specimen to specimen.

Wires of all three sizes have some initial curvature, making them difficult to handle and making it difficult to scribe gage marks on the specimens. The wire is also very hard, and a stress of 20 - 30,000 psi must be developed in a test before the grips of the machine bite into the wire sufficiently to secure it. The extensometer used to measure strains could not be attached until the wire had straightened and the grips were set. Therefore, those portions of the stress-strain curves in Fig. B14 below about 30,000 psi represent extrapolations from higher stresses.

Although the stress-strain curves of the wires in Fig. B14 do not show a well defined yield point, they do have fairly sharp breaks. The wires also have reasonably large elongations, as given in Table B9.

The elongation on a 10-in. gage length not including the region of fracture, plus about 0.75 percent strain to represent recovered deformation, should represent roughly the strain in the steel at fracture.

Two specimens of 0.196-in. wire, on which the galvanizing had been removed and the wires rusted, were tested. The tensile strength of these wires was lower in terms of maximum total load, but the ultimate tensile stress computed on the basis of a diameter of 0.192-in. was slightly higher -- 239,000 psi as compared to 234,000 psi for the galvanized wire.

These tests of wires will be continued as additional wire is obtained for use in the beam tests.

V. TESTS OF BEAMS

18. Measurements

The types of measurements of strains and deflections in the present series of tests have been selected with the object of studying the action of post-tensioned, bonded beams at all stages to failure and of obtaining data for determining the applicability of the analytical method of computing the ultimate flexural strength of such beams.

Strains were measured on the steel wire reinforcement, and on the top and sides of the concrete beams. Deflections were measured at midspan and at the one-third points. A complete summary of the locations of strain and deflection measurements is shown in Fig. B2.

Strains in the 0.196-in. steel wires were measured with type A12, SR-4 electric strain gages. These gages were waterproofed, with Petrolastic in Beam B1 and with Cycleweld C-14 Cement in Beams B2 and B3. Petrolastic is an asphaltic compound produced by Standard Oil of California. Cycleweld is a cement produced by Cycleweld Cement Products, Trenton, Michigan. The cement consists of a resin and an activator which form an extremely strong and waterproof coating when cured. The lead wires from the gages were carried down the grout channel to the end of the beam where they were brought out through the bearing plate and the slotted washers under the dynamometers. Strains were measured on two wires in Beam B1 and one in B2, and one in B3. The locations of these gages are shown in Fig. B2.

Strains in the concrete on top of the beam were measured with type A-9, SR-4 electric strain gages. The gages were arranged in a staggered line on Beams B2 and B3 in order to have continuous strain measurements over a 24 in. length at midspan. On Beam B1, strains were

measured only at midspan on the top surface of the beam. The arrangement of the gages is shown in Fig. B2.

Steel plugs, 1/2 in. in diameter and 1/2 in. long with gage holes drilled in one end, were cemented to the sides of the beam in order to measure the strain distribution over the depth of the beam. The arrangement of the plugs was such that continuous strain measurements could be made over a length of 18 in. in Beam B1, and 30 in. in B2 and B3. A 6-in. Berry strain gage was used to measure these strains on B1, and a 10-in. Whittemore strain gage was used in the tests of B2 and B3. A direct reading gage, employing a 0.001-in. dial micrometer was used after cracking developed to such an extent that the strains were beyond the range of the Berry and Whittemore gages.

Deflections at midspan were measured during the early stage of each test with a 0.001-in. Ames dial deflectometer. In the advanced stages of loading a steel rule was used, measuring from the base of the testing machine to paper targets cemented to the sides of the beams at mid-depth. The locations of these targets are shown in Fig. B2.

In addition, the stresses in the wires at the end of the beam were measured by means of the aluminum dynamometers at each increment of load. Cracks were marked at each load increment, and the development of each crack was traced by marking the number of the increment at the top of the crack.

19. Testing Procedure

In general, the procedure of preparing each beam for testing was as follows: the beam was moist cured for 7 days and then stored in the laboratory; the wires were pulled through the grout hole and

tensioned two days before testing; the grout was pumped in around the reinforcement immediately after tensioning; and the beam was tested two days after prestressing.

The tests were made with 12 to 23 increments of load, and required a total length of time of from 3 to 5 hours. The time required for strain and deflection readings at each increment was about 10 minutes. With the exception of one hour interruptions in the tests of Beams B2 and B3 during the noon hour, the next increment of load was applied immediately after the strain and deflection readings had been made. When the load was held for one hour, readings were taken before and after the interruption.

Generally there were about 4 equal increments of load up to the cracking load. Thereafter, increments were based on strain and deflection measurements rather than load. The beams were loaded until there was a general crushing of the concrete, and in B3 until fracture of the reinforcement had occurred.

20. Results of Tests

Typical results of the tests are reported in the form of graphs of load vs. midspan deflection, load vs. strain in concrete at the top of the beam, and load vs. strain in the reinforcement during the tests; and graphs of the strain distribution over the depth of the beam resulting from the tensioning of the reinforcement.

(a) Strains Due To Tensioning - Comparisons of observed and computed strains at tensioning and observed strains two days after tensioning are shown in Fig. B15. The solid circles represent the observed strain at tensioning; the solid triangles and solid line represent the computed strain at tensioning; and the open circles represent the observed strains

immediately before testing, two days after tensioning. Each observed strain is the average of the strains of all gage lines at that depth in the middle third of the beam. The theoretical stress was computed from the properties of the net concrete section and measured tensioning force in the reinforcement. The value of modulus of elasticity from tests of cylinders was used in converting computed stresses to strains. Since no measurements of modulus of elasticity were made on cylinders from Beam B1 and since the compressive strength was very close to that of B2, the measured value of modulus from Beam B2 was used in computations for B1.

Although the observed and computed strain values in Fig. B15 differ by large percentages in some instances, the differences are not consistant from beam to beam. For example, the computed strain at the bottom of the beam is about 20 percent greater than the observed strain at tensioning in Beam B1, about 15 percent less in B2, and about 20 percent greater in B3. However, the strains are fairly small and some of the discrepancy could be the result of inability to measure such small strains accurately.

The compressive strains observed two days after tensioning are consistently smaller than those observed at tensioning. The decrease could be explained by a loss of prestress as a result of creep of the reinforcement, but no loss large enough to account for the observed changes was indicated by the measurements of strain in the wires and dynamometers. It is believed that the decrease in compressive strains, or expansion at the bottom of the beam, was the result of an increased moisture content of the lower part of the beam caused by absorption of water from the fluid grout.

(b) Tensile Stress In Concrete At Cracking - Comparisons have been made of the tensile stresses in the concrete at first cracking, based on values computed from observed strains and those computed from the properties of the beam. Table B10 gives these values and the values of modulus of rupture from 6 by 6 by 18 in. beams. The values listed as computed stresses were based on the properties of the net concrete section for stresses due to tensioning and the transformed section for stresses due to the test loading. The tensile stresses listed as observed values were computed from the sum of the strains measured at tensioning and the strains caused by the applied load in the tests. The stresses occurring under test loading were computed from strain values which were extrapolated to the cracking load from the strains measured prior to cracking, since cracking always occurred between load increments. The changes in strains during the two days prior to testing were neglected. Strains were converted to stresses by use of the modulus of elasticity of control cylinders in compression. All stresses include the computed tensile stress resulting from the weight of the beam. The observed values for Beams B2 and B3 given in Table B10 are in good agreement with the modulus of rupture and also with the computed stresses for those beams. The agreement for Beam B1 is not as good, the computed value being higher while the observed value is much lower than the modulus of rupture.

(c) Strains and Deflections During Tests - Curves of load vs. midspan deflection, concrete strain at the top surface of the beam, and strain in the steel reinforcement are given in Figs. B16, B17, B18, and B19. Figure B16 shows the load-deflection curves for all increments of load, while the deflections for low loads are plotted to a larger scale

in Fig. B17. The maximum concrete strains on the top surface of the beam are given in Fig. B18. Strains measured in the wire reinforcement are shown in Fig. B19. There was some decrease in load during the time required for measurements at practically all stages of loading. The loads represented in all figures are those reached when loading was stopped to record measurements.

A short summary of each beam test is given below in order to illustrate the data plotted in the figures and the behavior of the beam under load.

Beam B1

Load No.	Load - lb	Observations
5	14,700	First cracking. Several cracks developed.
7	17,400	Bond slip extended to end of beams.
11	24,000	Washer under wire No. 7 failed.
12	23,200	Washer under wire No. 2 failed.
14	19,000	Concrete crushed immediately East of West loading block.
17	16,500	Compression crack well developed. Testing discontinued. Substantial recovery of deflection upon removal of load.

Beam B2

Load No.	Load - lb	Observations
3	10,090	First crack. Crack extends up to 3 in. below top.
4, 5, 6		Four cracks developed.
9	13,870	Slight crushing near midspan and immediately east of West loading block.
11	14,120	Crushing developed further near West loading block and at midspan. Crushing developed near East loading block. Load held for 2 min. and wedge of concrete in middle third of beam heaved out.

Beam B3

Load No.	Load - lb	Observations
4	6,220	First cracking 7 in. East of midspan.
15	6,760	Crack about 3/16 in. wide. Extended within 5/8 in. of top of beam.
17	7,050	Crushing 6 in. East of midspan directly over crack.
22	6,640	Wire No. 7 fractured. Crushing had developed over length of about 9 in.

The behavior of all beams was very nearly the same until the cracking load was reached, the beams acting as rectantular concrete sections until cracking. However, the beams behaved differently after cracking. Comparisons of the behavior of the beams may be made by a study of Figs. B16 and B17. The three beams were similar except for the percentages of steel and a lower concrete strength in Beam B3. Beam B1 was reinforced with eight 0.196-in. wires, B2 with four, and B3 with two. The load-deflection curves of the beams were fairly straight up to the cracking load, as is shown in Fig. B17. When cracking occurs there was an immediate increase in deflection without increase in load. Usually there was a drop in load which, however, is not shown in Fig. B17. The increase in deflection results from the elongation of the reinforcement necessary to develop the tensile force which the concrete and steel shared before cracking. After the tensile force is transferred from the concrete to the steel, the load-deflection curves have less slope, the behavior of the beams being similar to that of ordinary reinforced concrete beams.

The load at cracking in the test of Beam B3 was only slightly smaller than the maximum load observed, indicating that the tension carried by the concrete immediately before cracking was nearly equal to

the additional stress developed in the wire before failure. After first cracking in B3 the load was purposely reduced to about one-half the cracking load, and the beam was reloaded to establish the point at which the cracks would open. This point is shown in Fig. B17 as a distinct break in the load-deflection curve. Only one crack opened in B3, as shown in Figs. B20 and B21. Crushing occurred immediately over this crack after the crack had progressed to a point about 3/4 in. below the top of the beam. After first crushing, the crack closed for a short distance below the top of the beam, replacing the compression area lost by crushing. The curve for strain in the concrete in Fig. B18 does not show very large strains, although crushing occurred under the gage. The gage measured strain over 6 in., but the crushing was restricted at first to a length of about 1/2 in. A slightly larger load than the load at first crushing was developed in Beam B3; the maximum load was reached just before the spalling evident in Fig. B20 occurred. Loading was continued until one of the wires fractured. After the wire fractured, the beam still carried about 40 percent of the maximum load.

The behavior of Beam B2 was slightly different. Four major cracks formed as shown in Figs. B22 and B23. The numbers beside the cracks represent the location of the top of the crack at that particular load number. Crushing first occurred as a slight spalling near the center of the beam and near the west loading plate. Loading was continued until the maximum load was reached just before the wedge of concrete shown in Fig. B22 broke loose.

The analysis of the data obtained in the test of Beam B1 was difficult since the initial bond failure followed by failure of the end

anchorages introduced indeterminate factors. The next beam tested is to be a specimen having the same reinforcement and concrete strength as B1, but with rusted wires and grout with added aluminum powder.

The load-strain curves for strain in the wire reinforcement in Fig. B19 represents the strain measured by the A-12 gages on the wires until the gages failed, except in Beam B1 where readings were discontinued after the failure of the end anchorages of the wires with gages. The curves for strain in the concrete, Fig. B18, are maximum strains up to the increment before crushing.

(d) <u>Comparison of Observed and Computed Maximum Moments</u> - Values of maximum load, maximum moment and the dimensionless quantity $M/f_c'bd^2$ are given in Table B11. The maximum load represents the total load applied during the test, one-half of the load being transmitted to the beam at each third-point. The computed dead load moment is included in the value of the maximum moment.

Values of $Q = E_s p/f_c'$, are given for each beam in Table B1. This is done in order to illustrate the relative position of the beams with respect to tension and compression failures. The curves of $M/f_c'bd^2$ vs. Q presented in Section A indicate that all the beams tested were in the range of initial tension failures.

Values of $M/f_c'bd^2$ were computed for each beam, using the procedure given in Section A based on the actual stress-strain diagram for the steel. Values relating to the concrete stress block were taken as follows: $\epsilon_u = 0.0038$, $k_1k_3 = 1.0$, and $k_2 = 0.5$. The computed value of $M/f_c'bd^2$ for Beam B1 is 0.163; for B2 is 0.081; and for B3 is 0.066. The agreement of computed and test values is good. However, there is reason to believe

that there is some discrepancy in the value for B1. The steel strains shown in Fig. B19 indicate that the steel stress at maximum load for B1 was about 165,000 psi, corresponding to a value of $M/f_c'bd^2$ of 0.123. The steel strain given for B1 in Fig. B19 is the average of strains measured on wires 2 and 7 at midspan (Fig. B2). At the maximum load on B1, the dynamometer at the west anchorage of wire 7 failed, but the strain measured in wire 7 immediately after the dynamometer failed was nearly the same as that measured in wire 2, and the average of the two is plotted in Fig. B19. The steel stress corresponding to the maximum moment developed by B1 is about 220,000 psi, computed by assuming a distance from the center compression to the center of the steel of 8.3 in. This discrepancy indicates that the gages on the wires were faulty, or that the bond slip on these wires was such that the stress in the remaining 6 wires was much higher. Bond slip in all wires at loads well below the maximum load was indicated by an increase in the stress measured by the dynamometers at the west end of Beam B1.

The agreement of computed and measured values of moment should not be considered a general check of the validity of the analytical procedure given in Section A because some of the necessary assumptions were not fulfilled. Perfect bond was not realized, the tensile cracking of the concrete was not sufficiently extensive to reduce the tension carried by the concrete between cracks to a negligible amount. The agreement between computed and measured values is more probably due to the fact that beams with the small steel percentages used in these three tests will fail when the stress in the steel is near the ultimate tensile strength, and when the neutral axis is very close to the top of the beam. In such cases,

the distance between the center of compression and the center of tension can be estimated closely, making it possible to compute the ultimate moment with fair accuracy. The influence of the concrete strength on the value of $M/f_c'bd^2$ does not become very significant until larger percentages of reinforcement are used.

VI. FUTURE TESTS

The beams tested were exploratory specimens of a series designed to study the flexural behavior of post-tensioned, bonded beams. The primary variable in the present group of tests is the percentage of reinforcement. The steel percentage will be varied from a very small value as in Beam B3 to values large enough to produce compression failures while the steel is in the elastic range. Although most of the beams will be made with concrete having a strength of 5500 psi, some beams will be made with a concrete strength of 3500 psi in order to obtain large values of $Q = E_s p/f'_c$. The tensioning stress will be 120,000 psi for all beams in this series. One important and immediate objective of the first group of tests is to develop and determine the adequacy of equipment and techniques for tensioning, anchorage, and grouting.

The effect of the magnitude of the initial tensioning force in the reinforcement will be studied in future tests. The present series of tests with a tensioning stress of 120,000 psi will form the basis for this study and additional specimens having initial tensioning stresses below and above this value will be tested.

The compressive strength of the concrete will be included as a primary variable in another proposed series of tests. As with the series on the effect of initial tension, the present series of tests will form the basis for the series on the effect of concrete strength and additional specimens having different concrete strengths will be added.

The flexural behavior of beams with unbonded, end-anchored reinforcement is also to be studied in future tests. The percentage of steel, magnitude of tensioning stress, and concrete strength will be included

as variables in these tests.

All tests will be designed in so far as possible to determine the validity and applicability of the analytical method of computation of ultimate flexural capacity given in Section A.

TABLE B1

PROPERTIES OF BEAMS

Beam	Age at Test Days	b in.	d in.	h in.	As $in.^2$	p	f'_s psi	f'_c* psi	f_{si} psi	Q**
B-1	29	6.00	9.11	12.00	0.241	0.0044	234,000	5490	119,000	22.6
B-2	46	6.15	9.53	12.15	0.116	0.0020	239,000	5420	120,000	10.8
B-3	66	6.00	9.62	12.12	0.058	0.0011	239,000	3760	120,000	8.5

* Compressive strength of concrete in center portion of beam.

** $Q = \frac{E_s p}{f'_c}$

TABLE B2

CONCRETE MIXTURES

Beam	[1]Batch	Mix by wt c : s : g	c/w by wt	Slump, in.	[2]Compressive Strength, psi	[3]Modulus of Rupture, psi	Modulus of Elasticity, psi
B-1	1	1:2.3:3.8	2.15	0	4900	488	
	2	1:2.3:3.8	2.01	3/4"	5490	560	
B-2	1	1:2.7:4.5		3/4"	4300	595	
	2	1:2.7:4.5	1.66	2 1/2"	5420	688	4.08×10^6
B-3	1	1:3.1:5.2	1.45	1"	4180		
	2	1:3.1:5.2	1.45	1 1/2"	3760	604	3.28×10^6

[1]Batch 1 in outer quarters of beam. Batch 2 in middle of one-half of beam.

[2]Average of four 6" x 12" cylinders.

[3]Average of four 6" x 6" x 18" control beams for Batch 2; two for Batch 1.

TABLE B3

GROUT MIXTURES

Beam	Mix by wt c:s	Aluminum, percent of wt of cement	c/w by wt	*Compressive Strength psi
B-1	1:1	0	1.64	4390
B-2	1:1	0.009	1.98	3230
B-3	1:1	0.011	2.00	4500

* Average of four 2" x 4" cylinders.

TABLE B4

SIEVE ANALYSIS OF AGGREGATES

Lot	1 1/2"	3/4"	3/8"	Percentage Retained on Sieve No. 4	8	16	30	50	100	Fineness Modulus
				GRAVEL						
1	0	37	80	93	95	96				
2	0	23	64	93	97	98				
				SAND						
1				7	17	34	63	88	99	3.08
2				2	19	36	65	90	98	3.10
				GROUT SAND						
1				0	1	1	1	87	100	1.90

TABLE B5

TRIAL BATCH MIXES

Batch No.	Proportions by Weight Cement:Sand:Gravel	c/w by weight	Slump Inches
	TYPE I CEMENT		
Ia	1:5.79:7.33	0.80	2 1/2
Ib	1:3.78:5.48	1.20	1 1/2
Ic	1:2.22:3.69	1.85	2
Id	1:1.62:2.88	2.13	2 1/2
Ie	1:1.27:2.59	2.38	2 1/2
If	1:1.05:2.06	2.70	1 1/2
	TYPE III CEMENT		
IIIa	1:5.82:7.35	0.91	1
IIIb	1:3.77:5.58	1.37	1
IIIc	1:2.22:3.74	2.08	1 1/2
IIId	1:1.30:2.59	2.22	1 1/2
IIIe	1:1.11:2.46	2.56	0
IIIf	1:0.80:1.40	2.94	0

TABLE B6

RESULTS OF TESTS OF BUTTON HEADS

Specimen No.	Type of Steel in Washer	Length of Washer	Chamfer in Washer	Type of Failure	Stress in Wire at Failure, psi
1H4	Hot Rolled	1/2"	None	Fracture below head	157,000
2H4	Hot Rolled	1/2"	None	Fracture in head	190,000
1H4F	Hot Rolled	1/2"	See Fig.B9	Head pulled through washer	193,000
2H4F	Hot Rolled	1/2"	See Fig.B9	Head pulled thru washer	211,000
3H4F	Hot Rolled	1/2"	See Fig.B9	Fracture in head	199,000
1H2F	Hot Rolled	1/4"	See Fig.B9	Fracture below head	198,000
2H2F	Hot Rolled	1/4"	See Fig.B9	Fracture below head	199,000
3H2F	Hot Rolled	1/4"	See Fig.B9	Washer split	202,000
1C4F	Cold Rolled	1/2"	See Fig.B9	Fracture in head	207,000
2C4F	Cold Rolled	1/2"	See Fig.B9	Washer split	199,000
3C4F	Cold Rolled	1/2"	See Fig.B9	Fracture in threads below head	195,000
1C3F	Cold Rolled	3/8"	See Fig.B9	Fracture in head	223,000
1B4F	High Str. Bolt Stock	1/2"	See Fig.B9	Fracture in head	178,000
1B2F	High Str. Bolt Stock	3/8"	See Fig.B9	Fracture in head	174,000
1B2F	High Str. Bolt Stock	1/4"	See Fig.B9	Fracture in head	199,000
1D4F	Unhardened Drill rod	1/2"	See Fig.B9	Fracture in head	191,000

TABLE B7

RESULTS OF TESTS OF THREADED WIRES

(All wires 0.196" diameter)

Specimen No.	Maximum Stress in wire, psi	Size Thread	Type of Nut	Type of Failure
1	48,500	10-32	1/2"Cold Rolled-5/8" Long	Nut stripped off Poor threads in nut
2	49,700	10-32	do.	do.
3	200,000	12-24	4 machine nuts	Fracture in threaded portion below nut.
4	206,000	12-24	do.	do.
5*	199,000	12-24	do.	Nuts stripped off.

*Load held at 166,000 psi for 15 minutes.

Failed after 1 minute at 199,000 psi.

TABLE B8

PROPERTIES OF BOND SPECIMENS

Specimen No.	Mix c:s	c/w	Al in % of wt of cement	Wire Surface	Avg Compressive Strength of 2"x4" cyl psi
1	1:1	1.64	0	Galv	2820
1A	1:1	1.64	0.011	Galv	1340
2	1:1	1.64	0	Galv removed	2450
2A	1:1	1.64	0.011	Galv removed	1350
3	1:1	2.00	0	Wire rusted	4500
3A	1:1	2.00	0.011	Wire rusted	2120

TABLE B9

PROPERTIES OF HIGH TENSILE STRENGTH WIRE

Diameter in inches	Stress at 0.2% offset psi	Ultimate Strength psi	% Elongation in 10 in. Including Fracture	% Elongation in 10 in. Outside Fracture	% Reduction in area	Modulus of Elasticity psi
0.099	252,000	279,000	4.0	2.9	28%	29.1×10^6
0.196*	195,000	234,000	6.7	5.1	32%	28.2×10^6
0.276	212,000	248,000	5.0	3.8	42%	30.1×10^6

* Includes galvanizing

TABLE B10

COMPARISON OF TENSILE STRENGTH OF CONCRETE

WITH MODULUS OF RUPTURE

Beam	B1	B2	B3
Computed Tensile Stress at Cracking Load, psi	690	670	530
*Observed Tensile Stress at Cracking Load, psi	310	710	590
Modulus of Rupture of 6"x6"x18" Beams, psi	560	690	600

* Computed from strains.

TABLE B11

RESULTS OF TESTS OF BEAMS

Beam	Pmax lb	Mmax ft-lb	$\frac{M_{max}}{f'_c bd^2}$ Measured	$\frac{M_{max}}{f'_c bd^2}$ Computed
B1	24,000	36,750	0.161	0.163
B2	14,120	21,960	0.087	0.081
B3	7,080	11,350	0.065	0.066

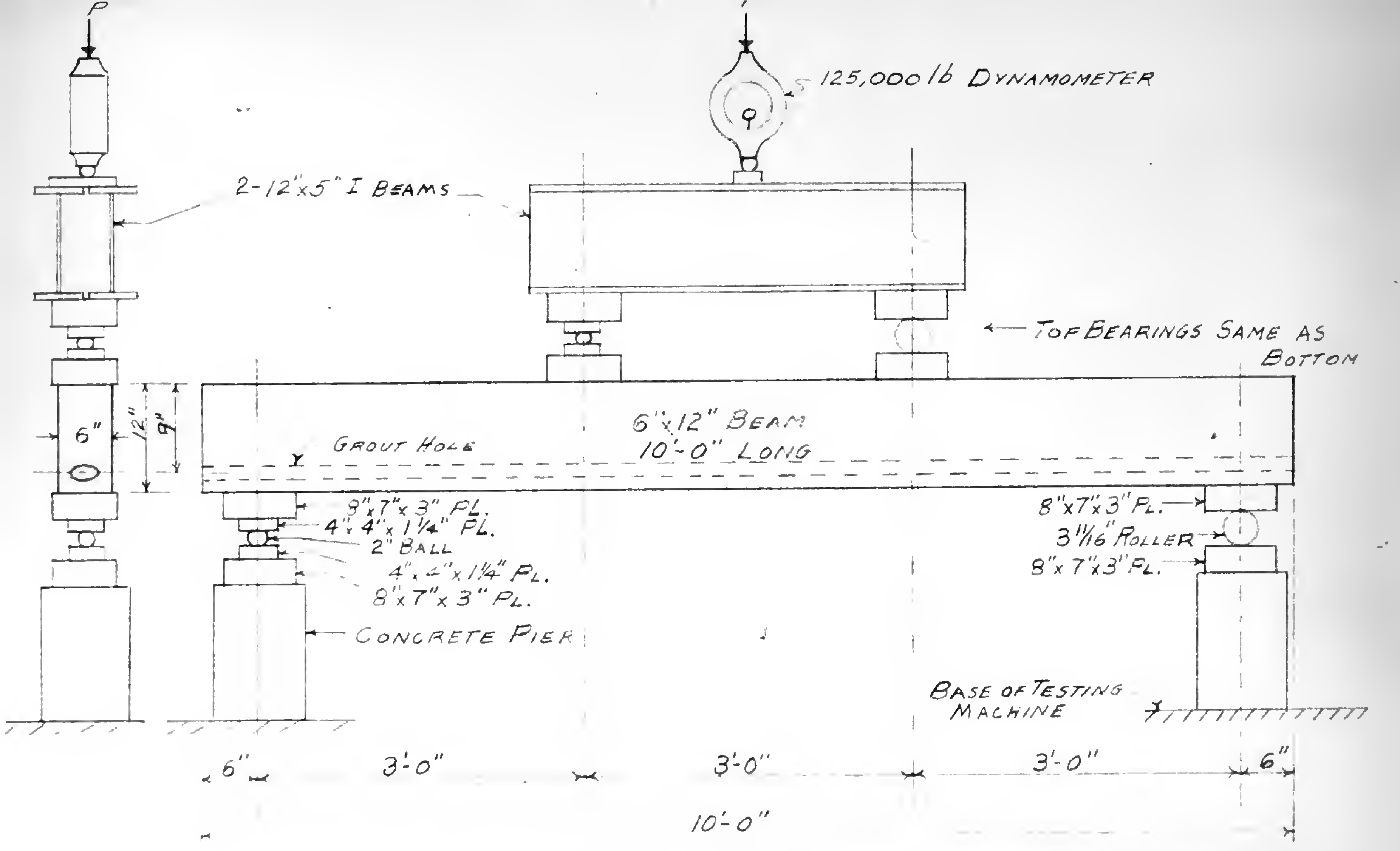


FIG. B1 - BEAM AND TESTING APPARATUS

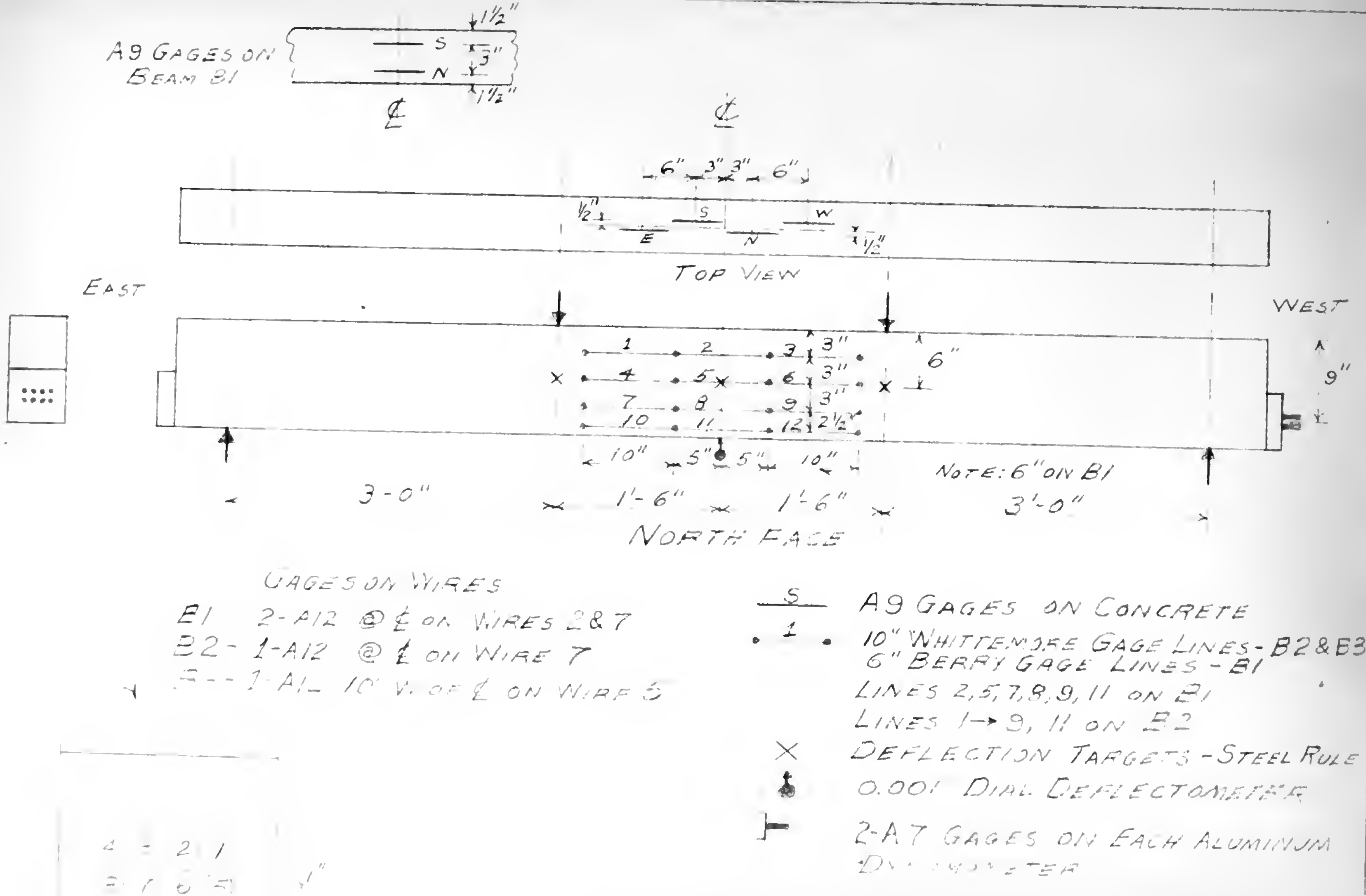
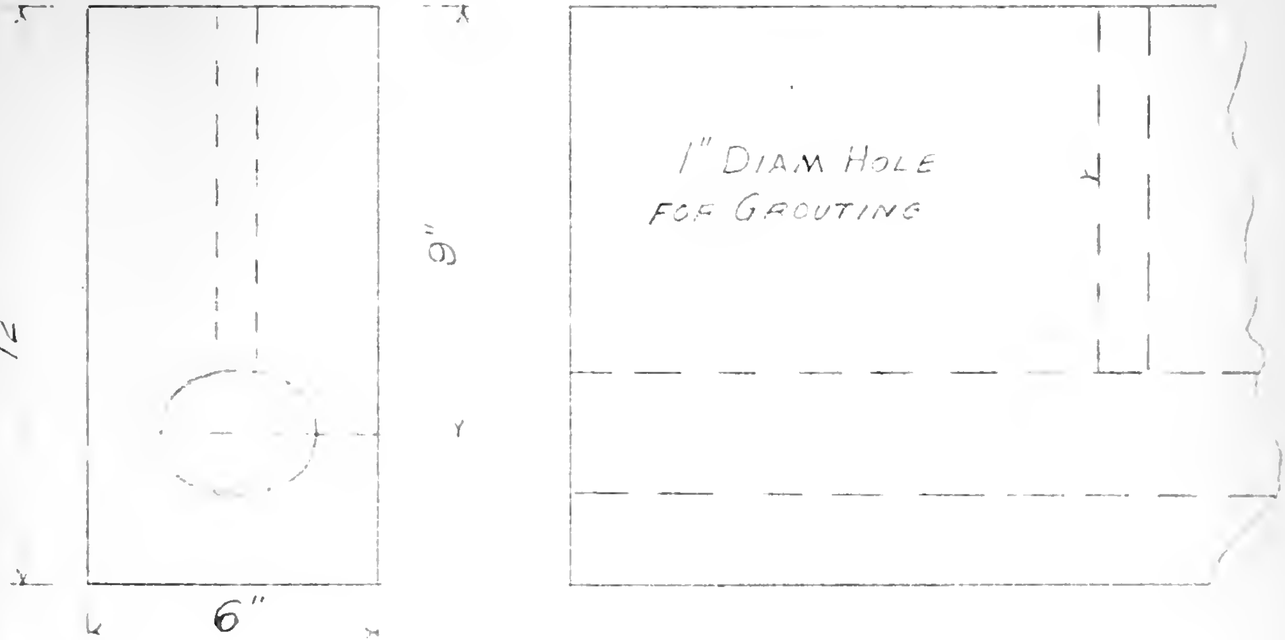


FIG B2 - MEASUREMENT LOCATIONS



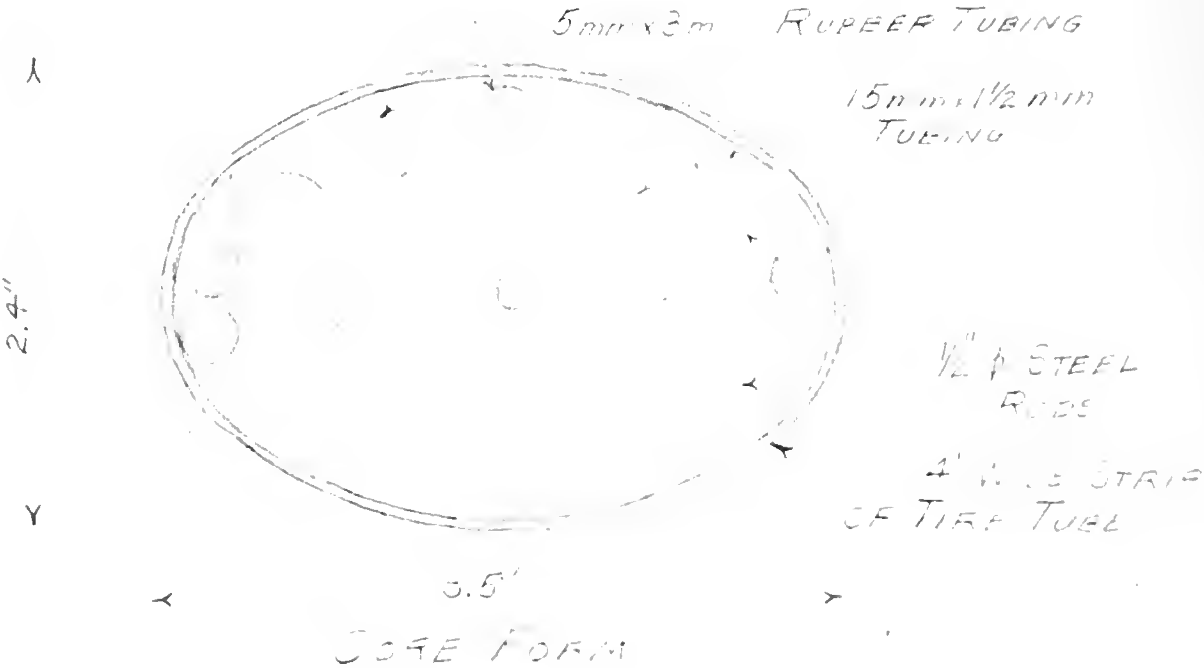


FIG.B3 DETAILS OF

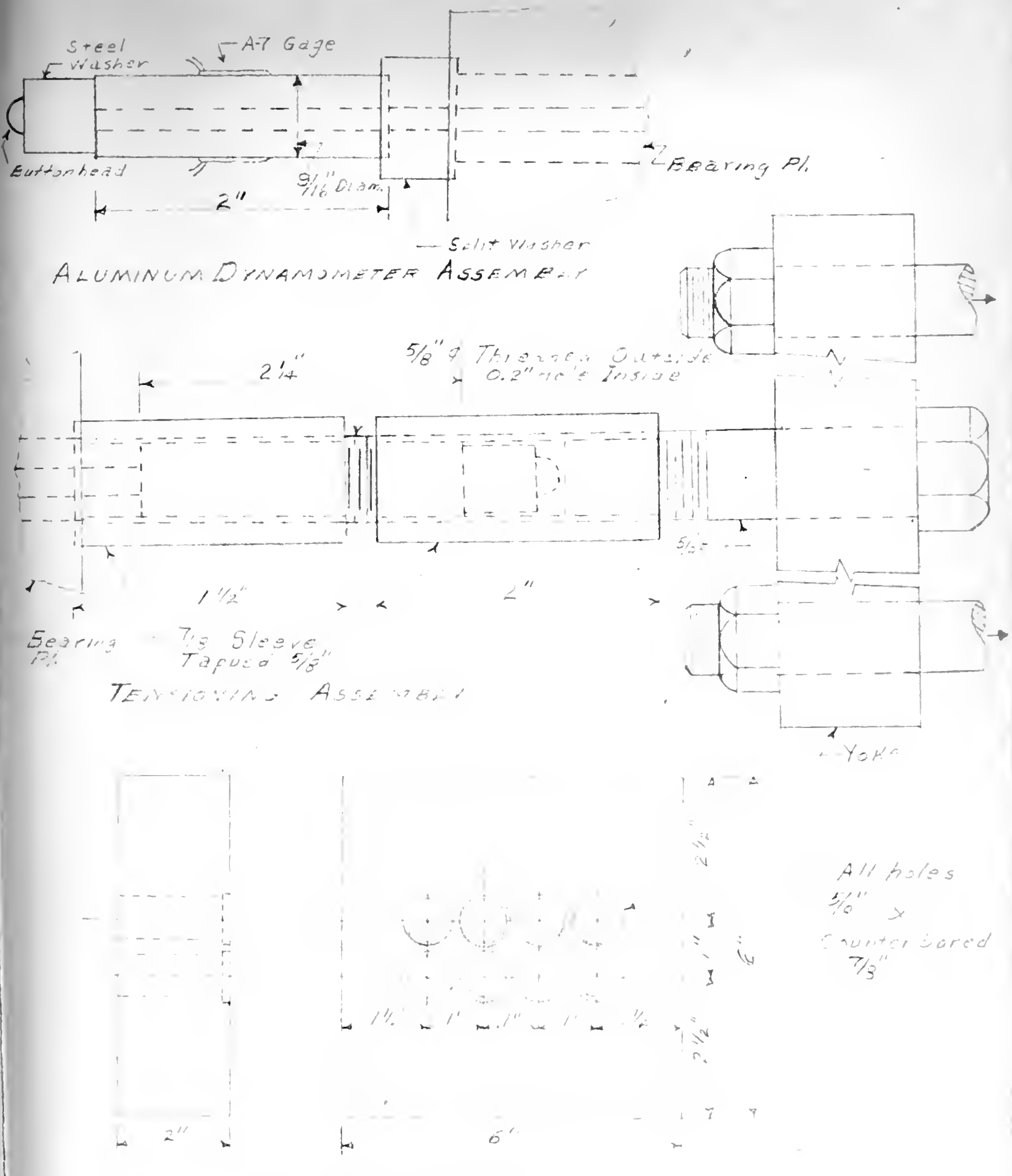


FIG. B4 ANCHORAGE DETAILS

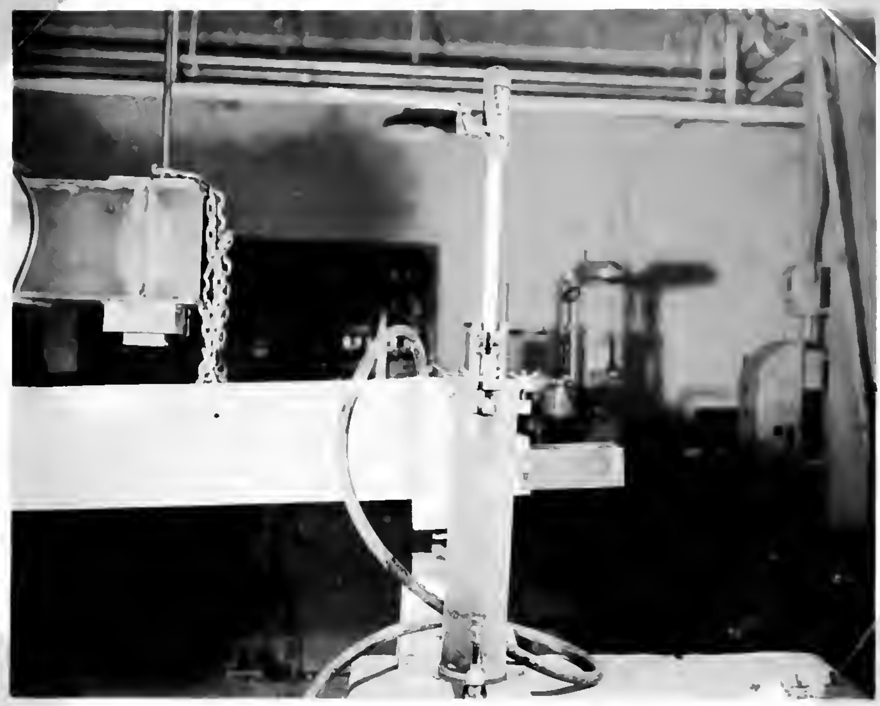


FIG. B5. VIEW OF GROUT PUMP

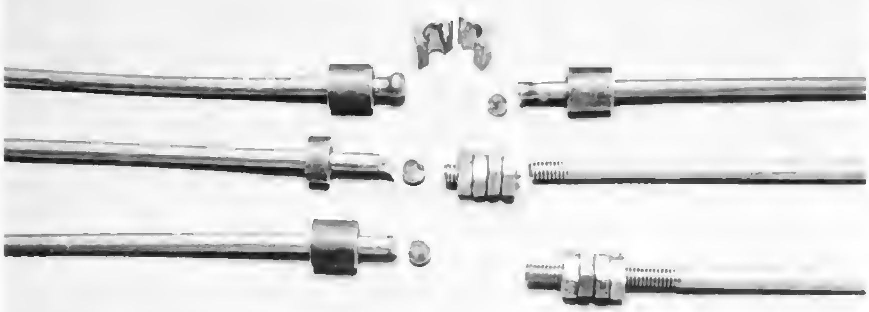


FIG. B6. VIEW OF END DETAILS OF WIRES

FIG. B7. VIEW OF HEADING APPARATUS

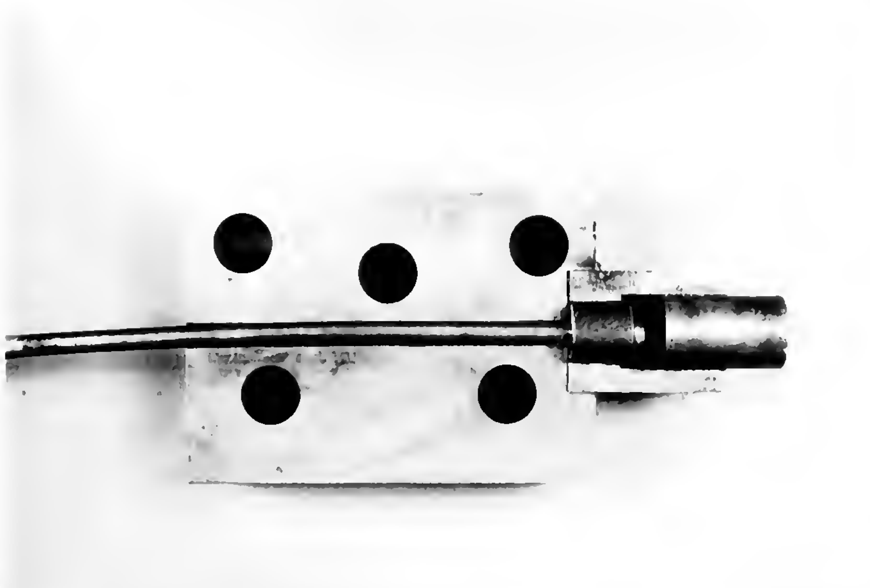


FIG. B8. INTERIOR VIEW OF HEADING APPARATUS

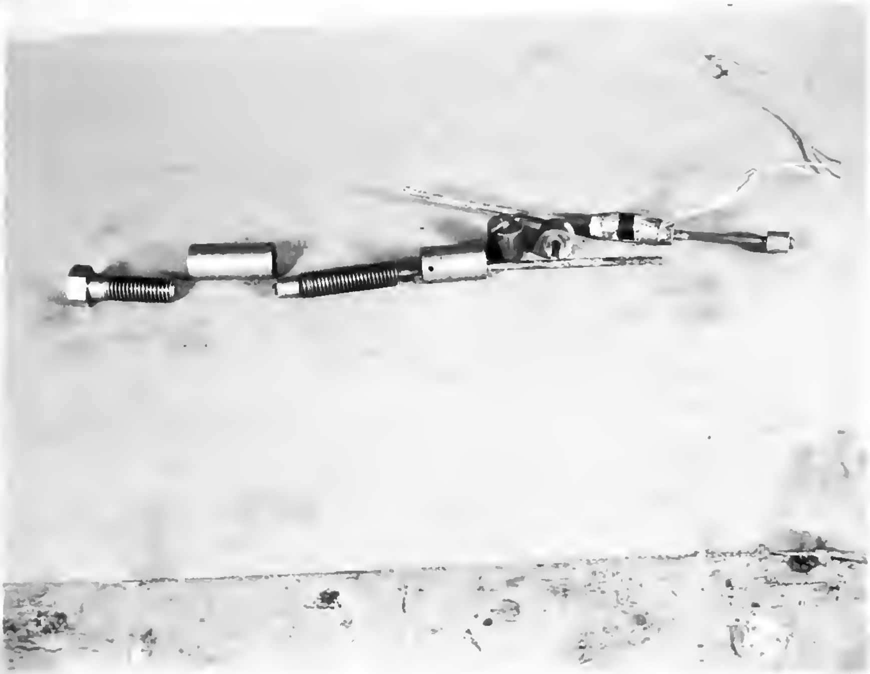
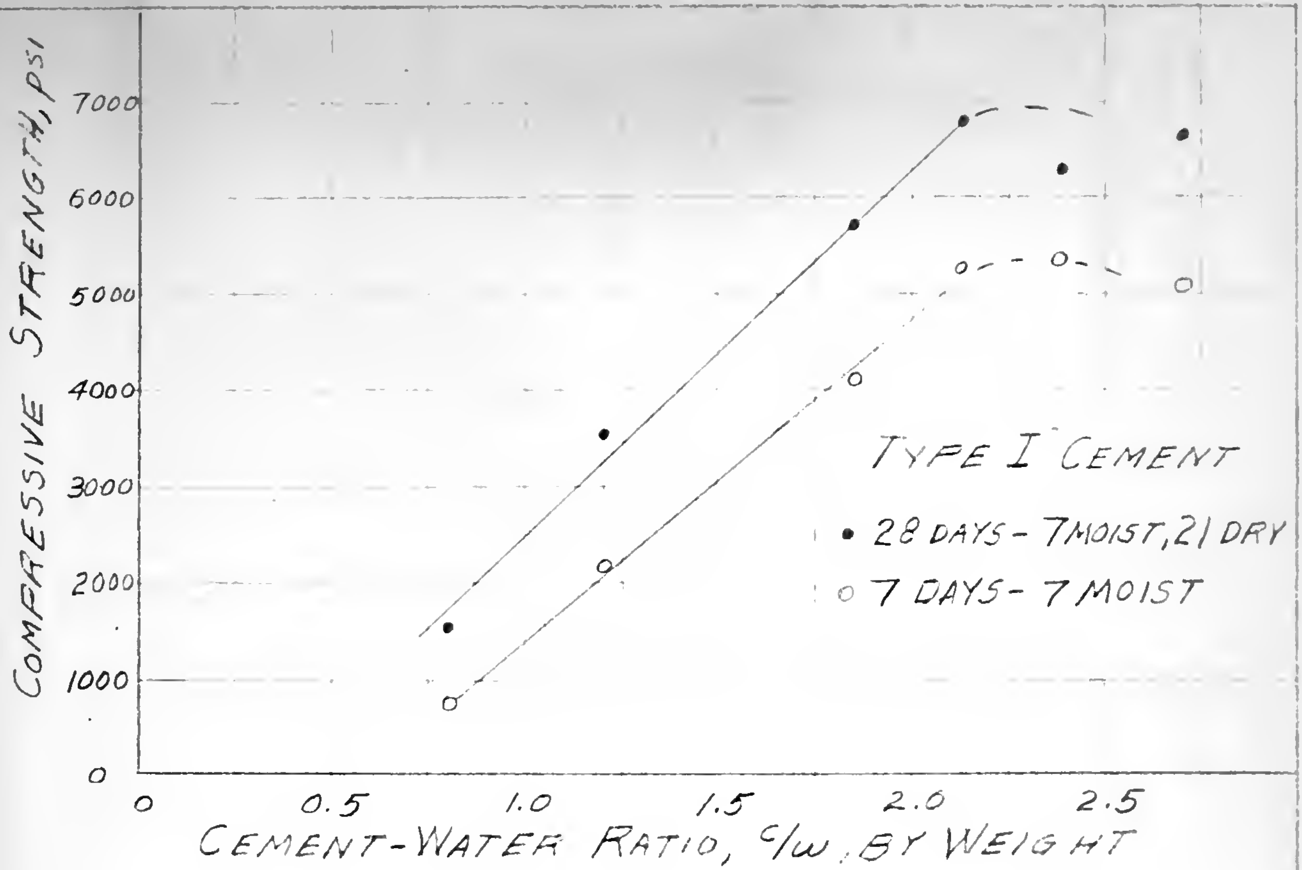


FIG. B10. VIEW OF SHIMMING DEVICE AND DYNAMOMETER

FIG. B11. VIEW OF TENSIONING RIG



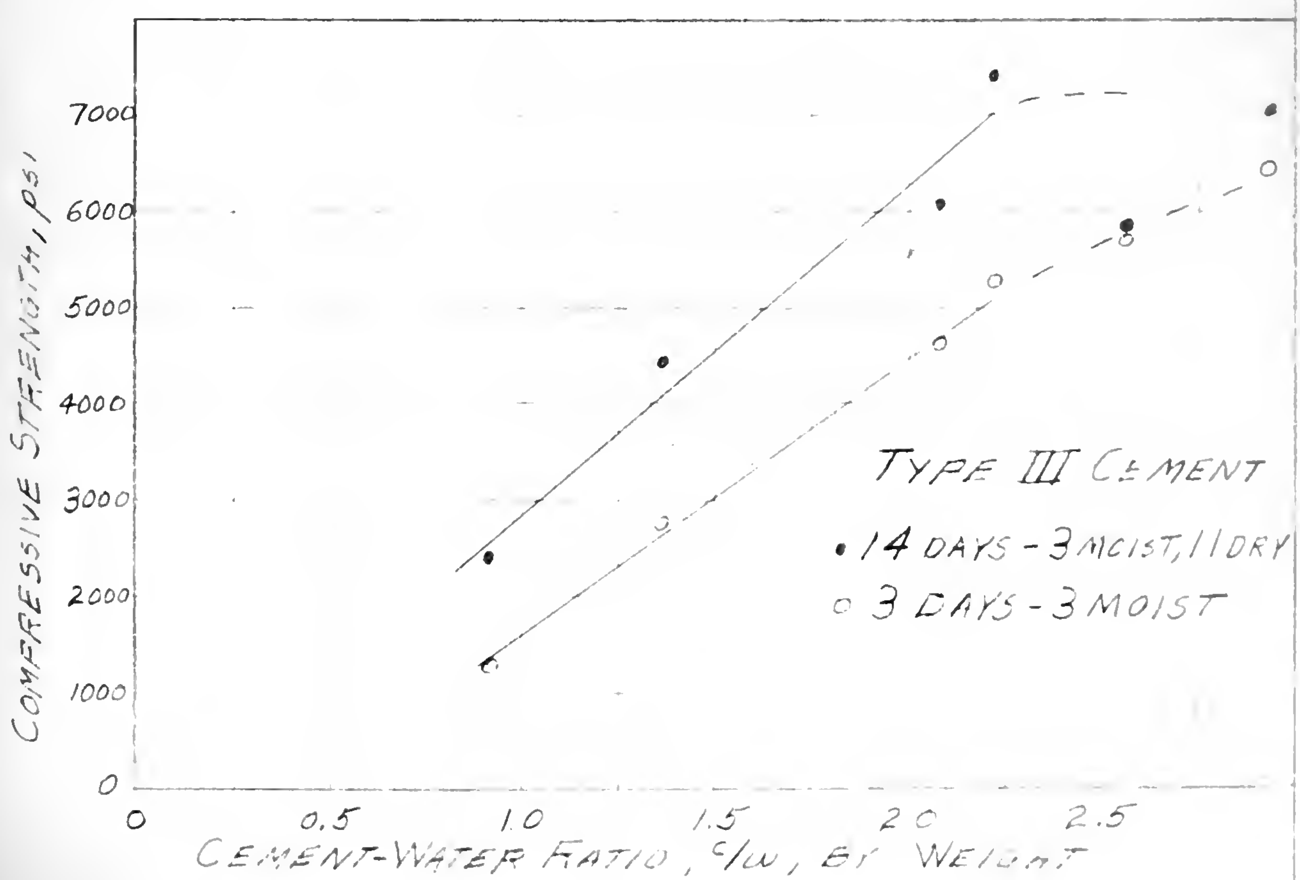


FIG. E12 - TRIAL BATCHES

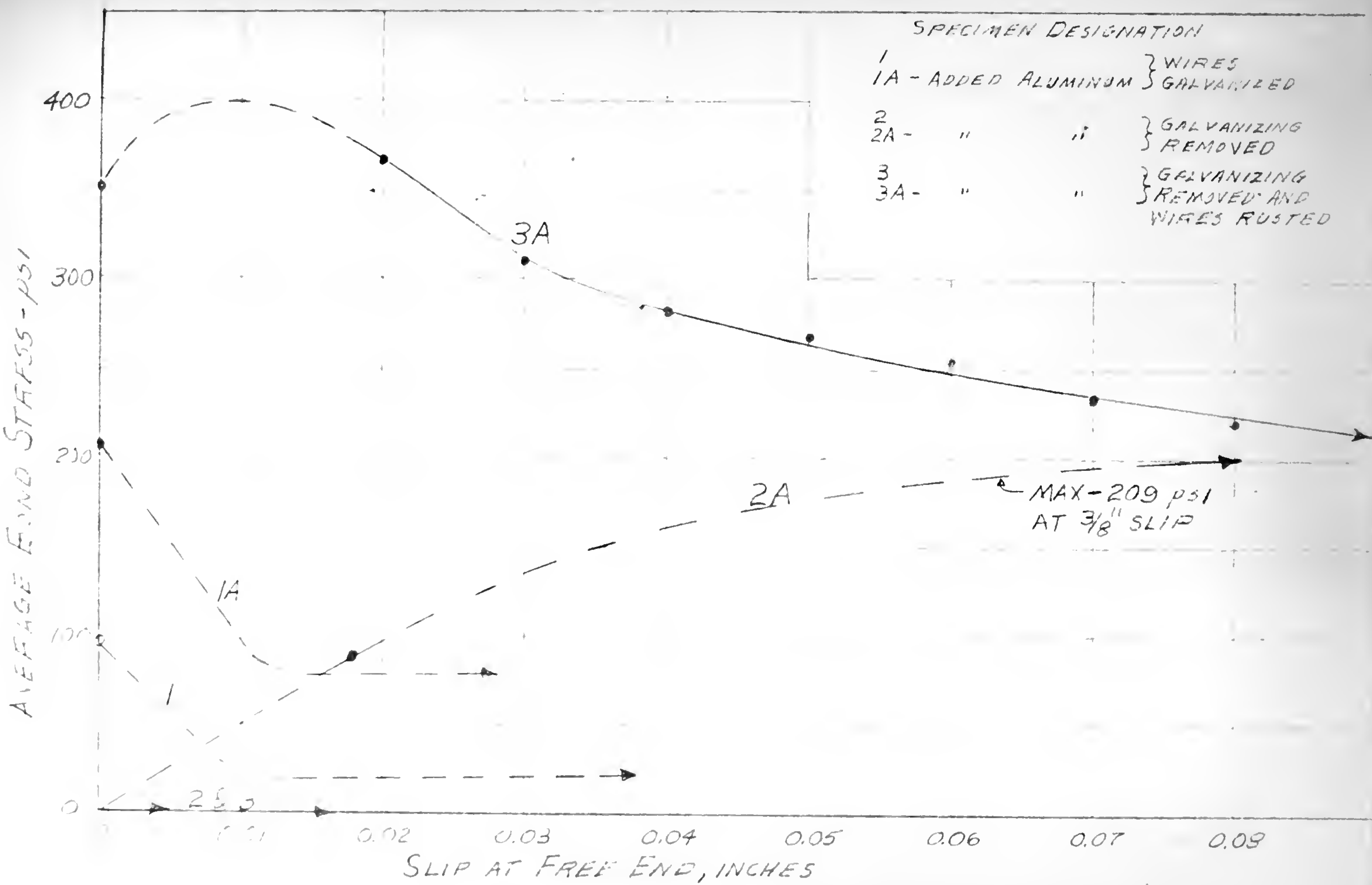


FIG E13 BOND TESTS

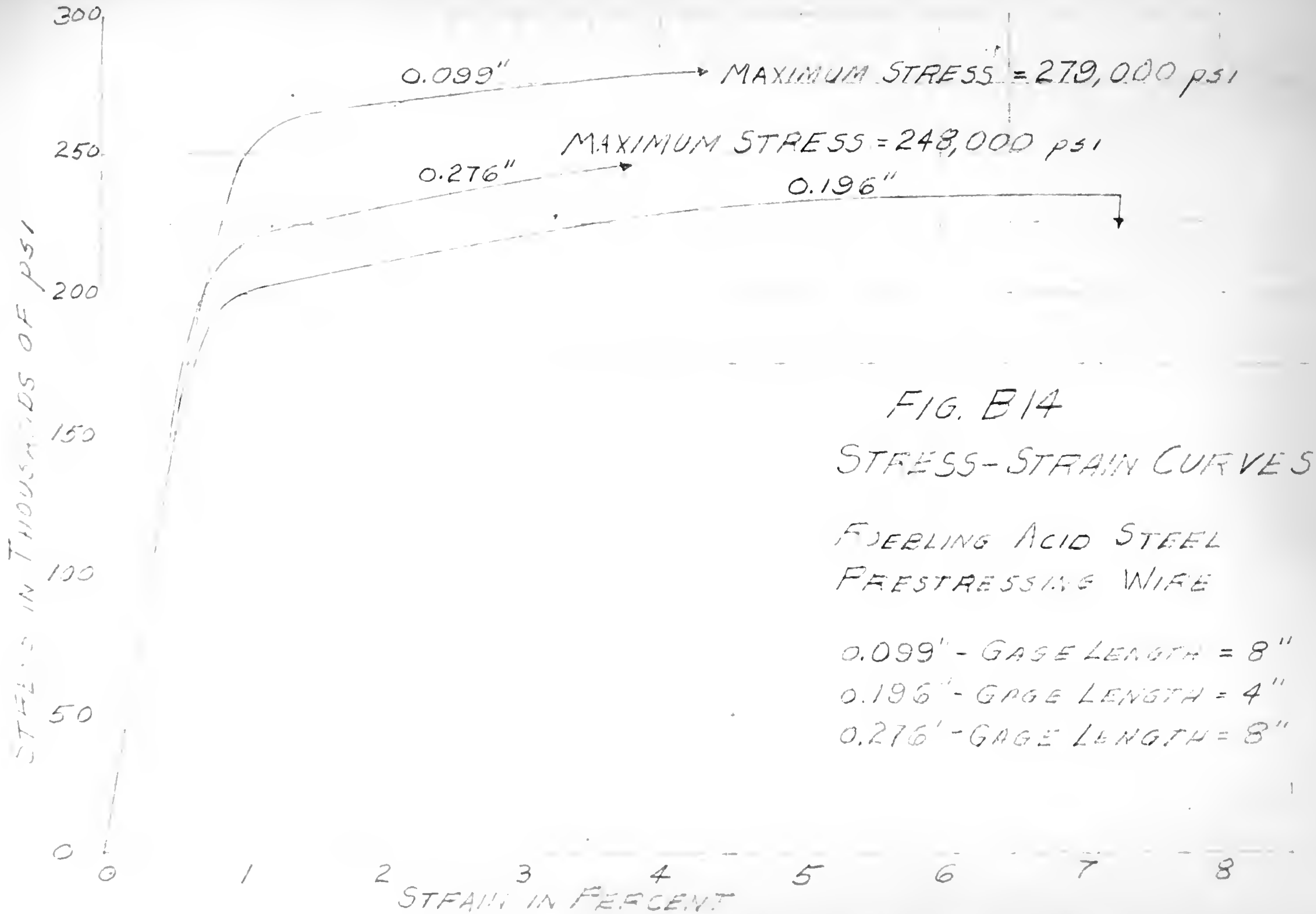
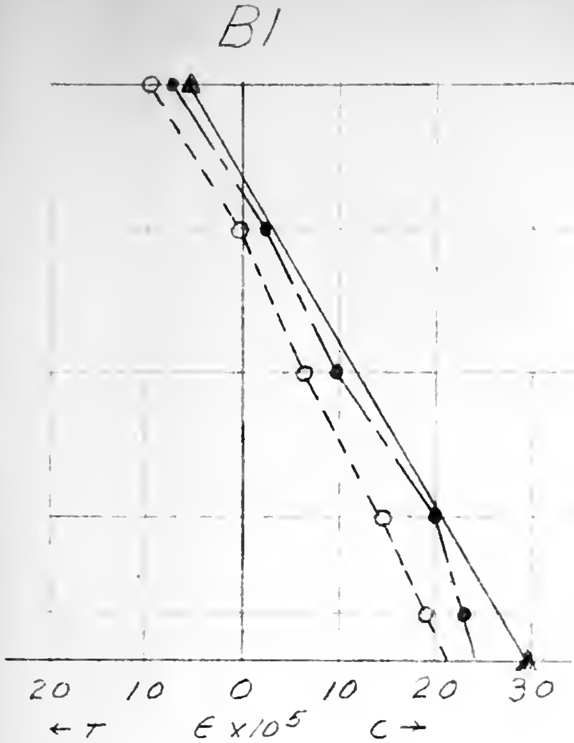


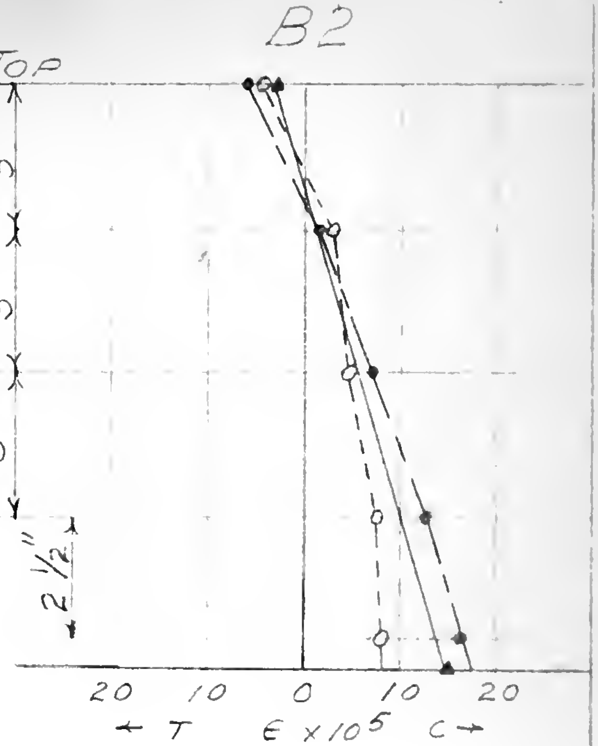
FIG. B14

STRESS-STRAIN CURVES

ROEBLING ACID STEEL
PRESTRESSING WIRE

0.099" - GAGE LENGTH = 8"
0.196" - GAGE LENGTH = 4"
0.276" - GAGE LENGTH = 8"





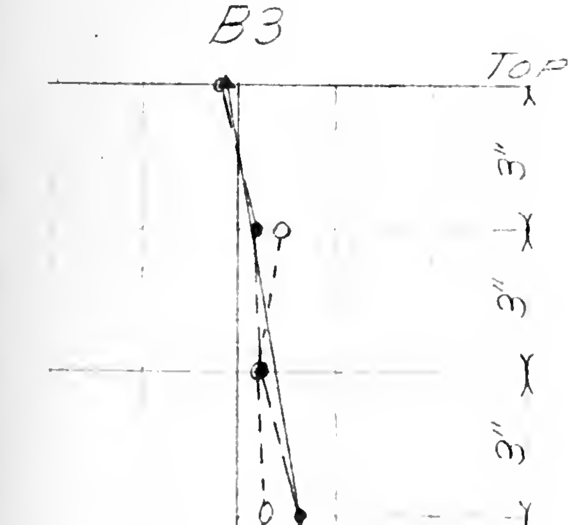


FIG. B15
CONCRETE STRAIN DISTRIBUTION AT MIDSPAN

COMPUTED STRAIN AT TENSIONING

OBSERVED STRAIN AT TENSIONING

OBSERVED STRAIN AT TEST

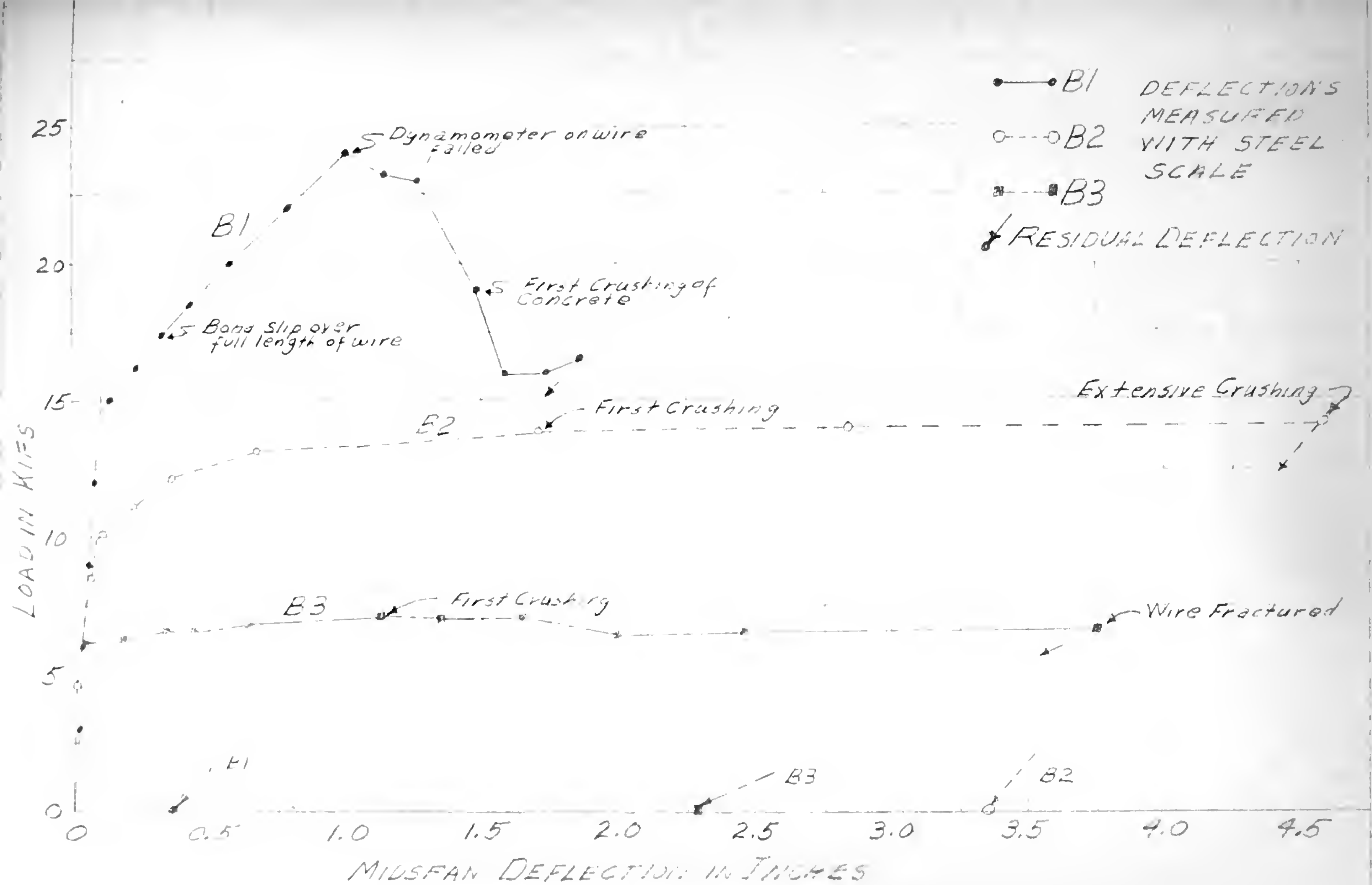


FIG. B16 MIDSPAN BEAM DEFLECTIONS

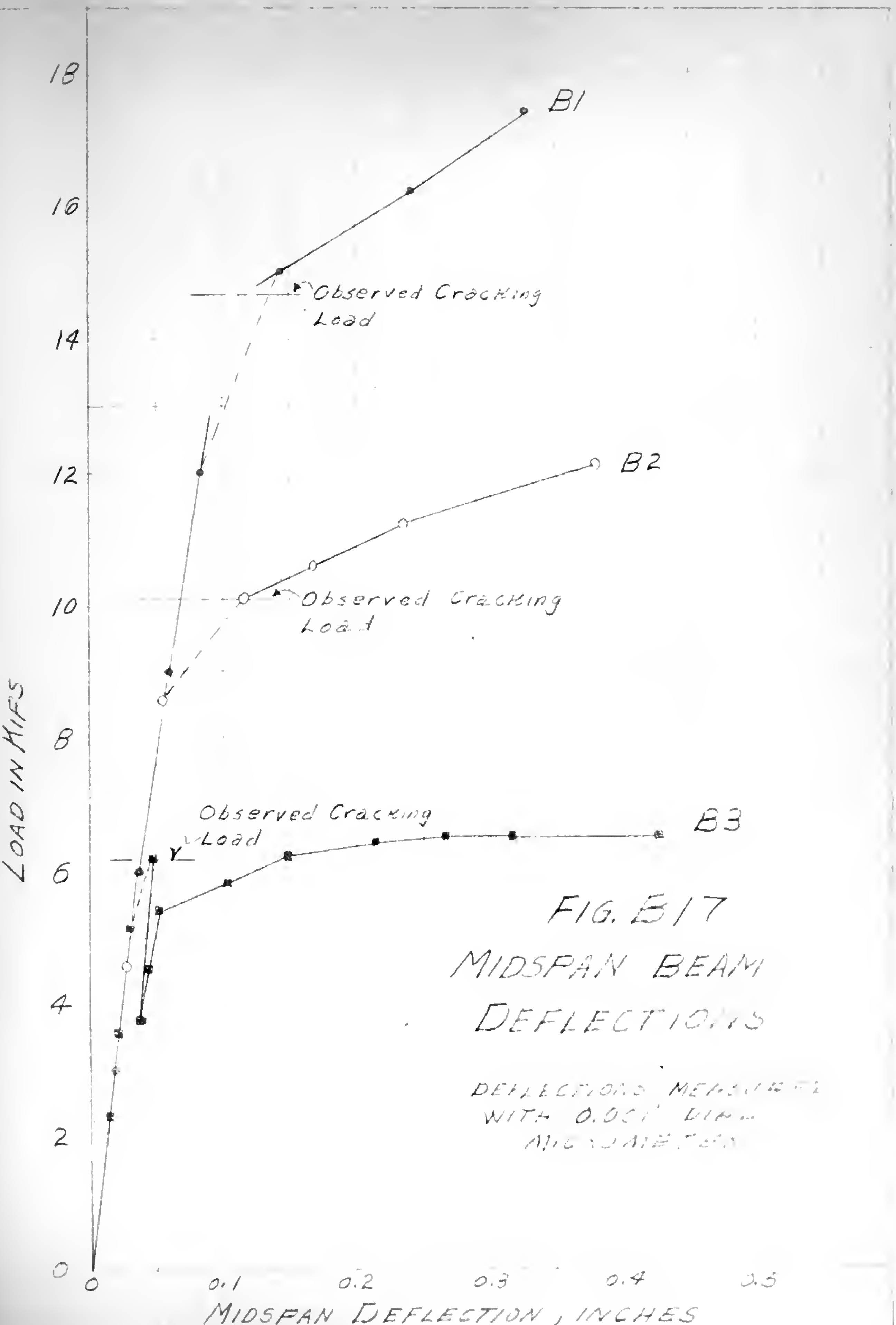


FIG. B17
MIDSPAN BEAM DEFLECTIONS

DEFLECTIONS MEASURED WITH 0.001" DIAL MICROMETER

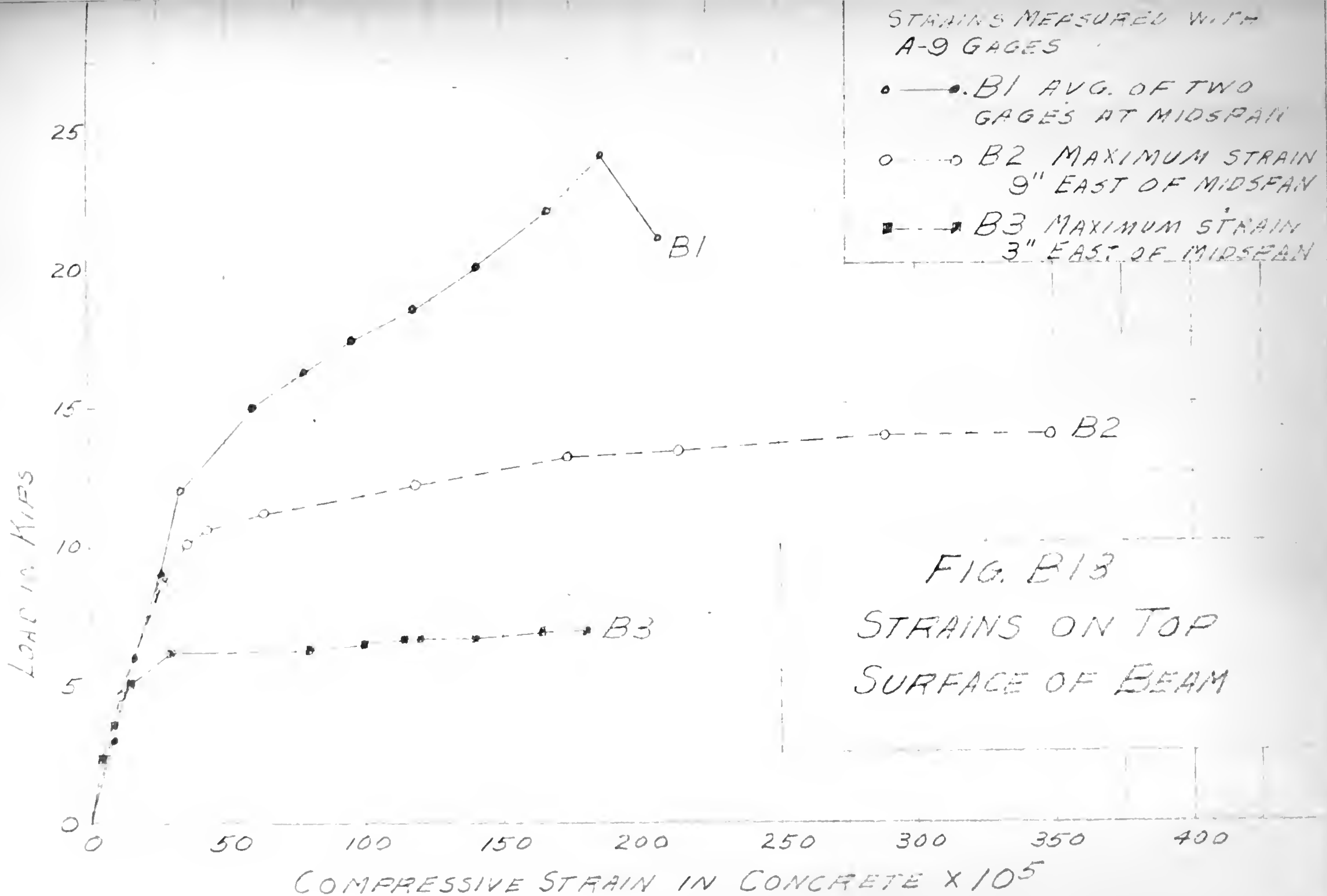


FIG. B13
STRAINS ON TOP
SURFACE OF BEAM

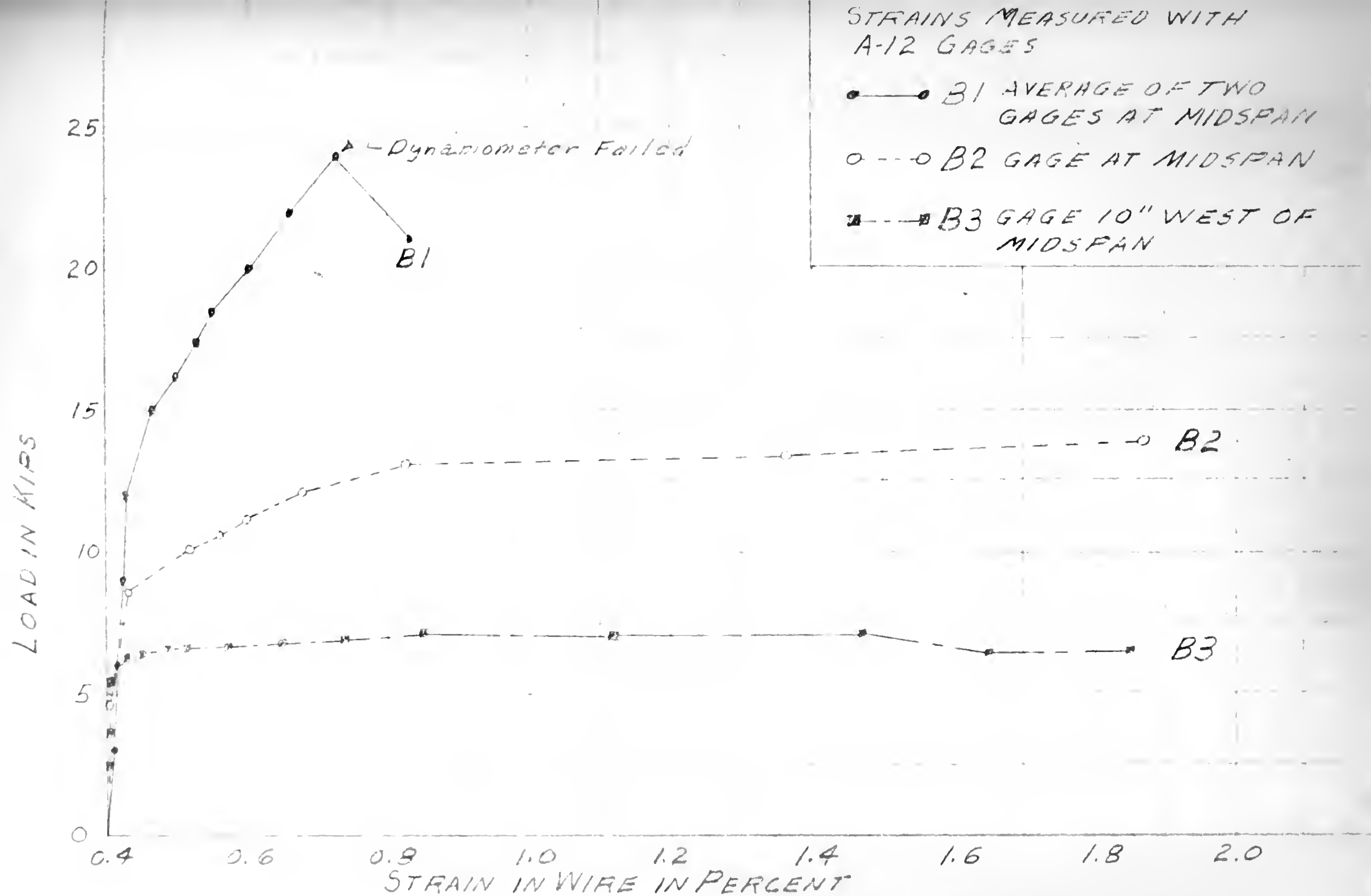


FIG. B19 STRAIN IN WIRES

FIG. B20. VIEW OF BEAM B3 AFTER FAILURE

FIG. B21. BEAM B3 IN TESTING MACHINE AFTER FAILURE

FIG. B22. BEAM B2 IN TESTING MACHINE AFTER FAILURE

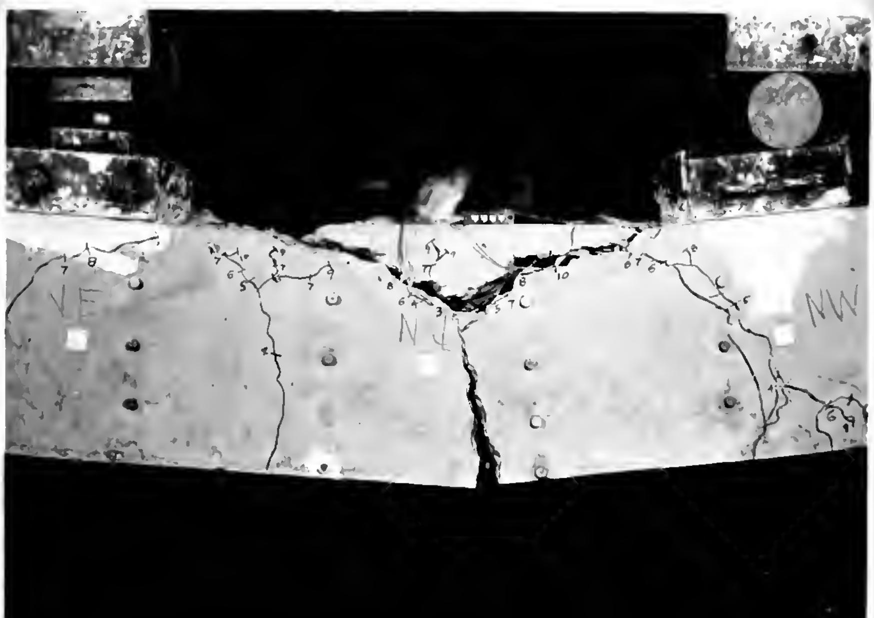


FIG. B23. VIEW OF BEAM B2 AFTER FAILURE

SECTION C

BIBLIOGRAPHY ON PRESTRESSED CONCRETE

By

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and

I. M. Viest

April, 1952

BIBLIOGRAPHY ON PRESTRESSED CONCRETE

All references included in this Bibliography are classified into six groups. The full title of references which contain material falling into several groups appears in one group only; in other groups cross-reference is made by number only.

A. Research

This group includes references on theoretical and experimental investigations of the materials for and the behavior of prestressed concrete structural members and structures.

B. Construction

This group includes references describing construction and manufacture of prestressed concrete structures; the prestressing methods; and finished structures of prestressed concrete.

C. Design

This group includes references on the design of prestressed concrete structures; it includes also specifications, economical studies and general textbooks on prestressed concrete.

D. Miscellaneous

This group includes general references on prestressed concrete and all references which do not fall into any other group.

E. Circular Structures

References concerned with circular structures, such as tanks,

pipes, pressure vessels and tunnels, are included in this group.

F. Unclassified

This group includes references which were not available to the authors of this bibliography and therefore could not be classified.

A. Research.

1896-1935

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Section III of this paper (pp. 605-606) deals with prestressing of reinforcement for the purpose of counteracting the deficiency of concrete in tensile strength. It is suggested that prestressing may be done by stretching the wires mechanically or by heat. Historically interesting.

A2. Bach, C.; Graf, O., "Versuche mit Balken, deren Eiseneinlagen Vorspannung Besitzen, und mit Balken derselben Bauart ohne Vorspannung," Mittëilungen über Forschungsarbeiten (Berlin), 1910, No. 90-91, pp. 61-86.

Tests of 12 rectangular beams, 6 prestressed, 6 without prestressing, 3 of each with end anchorages. Steel of structural grade pre-tensioned to 600 kg/cm^2, the prestress transferred to concrete 6 hours before the test. Results: prestressing raised the cracking load by about 50 percent, but the ultimate was the same for both prestressed and ordinary reinforced beams. End anchored beams failed by crushing of concrete, others by bond. Measured: Deflections, some strains, loads at first cracking, ultimate loads. Data on materials given, tests description good.

A3. Moersch, E., "Der Eisenbetonbau," Vol. 1, Fifth Edition, Stuttgart 1920, pp. 371-377, (K. Wittwer).

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A4. Freyssinet, E., "Idees et Voies Nouvelles", Science et Industrie (Paris), 1933, Vol. 17, No. 1, pp. 1-17.

Freyssinent presents his theory of hardening of concrete. Description of curing concrete under pressure and steam. Discussion of the use of high strength steel in prestressed concrete and why it cannot be used in ordinary reinforced concrete. Examples of structures of prestressed concrete. Emphasis on the economy of prestressed concrete and of its applicability in the industry.

A5. Hatt, W. K., "Concrete Beam with Prestressed Bars Tested", Engineering News Records, September 13, 1934, Vol. 113, No. 11, p. 345.

Comparative test of a reinforced concrete beam and a prestressed unbonded beam. The initial prestressed of the mild steel did not exceed 15,372 psi. Scant information given in form of moment-strain and moment-deflection curves.

A6. Anderegg, F. O.; Dalzell, C. L., "Prestressed Ceramic Members" Proceedings Amer. Soc. Test. Materials, 1935, Vol. 35, pp. 447-456.

Ceramic tile grouted together and prestressed with solid rods by tightening the end nuts. Beams were short and failed by diagonal tension. Test results for 8 beams. Properties of materials uncertain.

1936

A7. Freyssinet, E., "Aspects nouveaux des problemes du ciment armé", International Association Bridge and Structural Engineering, Publications, Vol. 4, pp. 265-304, 1936.

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A8. Freyssinet, E., "Developments in Concrete Making," Concrete and Construction Engineering, (London), 1936, Vol. 31, No. 4, pp. 209-220.

Essentially the same as "A Revolution in the Technique of the Utilization of Concrete".

A9. Gueritte, T. J., "A New Technique of Concrete Construction", Transactions, Liverpool Engineering Society, 1936, Vol. 58, pp. 125-160.

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A10. Lossier, H., "Les ciments sans retrait et a expansion", Genie Civil (Paris), 1936, Vol. 109, No. 14, pp. 285-87.

This article is an extract of the paper "Les ciments sans retrait et a expansion" published by the same author in Revue Universelle des Mines, 1937.

A11. Thomas, F. G., "Cracking in Reinforced Concrete", International Association of Bridge and Structural Engineering, Second Congress, Preliminary Publications, Berlin, 1936, (W. Ernst).

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1938

A12 Senn, A., "Die Wirksamkeit der Vorspannung im einfach und im symmetrisch bewehrten Eisenbeton-Rechteckquerschnitt", Schweizerische Bauzeitung (Zurich), 1938, Vol. 111, No. 6, pp. 61-62.

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1939

A13 Anderegg, F. L.; Weller, R.; Fried, B., "Photoelastic Analysis of Prestressed Beam", Proceedings of American Society of Testing Materials, 1939, Vol. 39, pp. 979-986.

Photoelastic analysis of the stress distribution in nonprestressed beams and prestressed beams at zero stress in top fibres, zero stress in bottom fibres and with tension in bottom fibres.

A14. Emperger, F. von, "Stahlbeton mit vorgespannten Zulagen aus Höherwertigem Stahl", Forscherarbeiten auf dem Gebiete des Eisenbetons, Heft 47, Berlin 1939, (W. Ernst).

Report of tests of reinforced concrete rectangular and T-beams with varying amounts of reinforcement added. Magnitude of prestress varied from 0 up. Principal findings: the ultimate load may be calculated by adding the yield strength of the ordinary steel and the ultimate strength of the high strength steel; the ultimate is independent of the amount of prestress; prestress is very effective in delaying and reducing cracking.

A15. Emperger, F. von, "Vorgespannte Armierungs-Zulagen in den Tragwerken aus Eisenbeton", Schweizerische Bauzeitung (Zurich), 1939, Vol. 114, No. 13, pp. 151-153.

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A16. Hoyer, E.; Friedrich, E., "Beitrag zur Frage der Haftspannung in Eisenebtonbauteilen", Beton und Eisen (Berlin), 1939, Vol. 38, No. 6, pp. 107-110.

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A17. Mills, R. E.; Miller, W. B., "Prestressed Reinforced Joists under Loading Tests", Proceedings, American Concrete Institute, 1939, Vol. 36, No. 11, pp. 205-212.

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A18. Abeles, P. W., "Saving Reinforcement by Prestressing", Concrete and Construction Engineering, (London), 1940, Vol. 35, No 7, pp. 328-333.

Theory for beams at low loads. Short description of prestressing methods.
Discussion by Mautner, ibid, 1941, Vol. 36, pp. 73-95.

A19. Opperman, R., "Grundlagen für die Ausführung von Spannbetonträgern", Beton and Eisen (Berlin), 1940, Vol. 39, No. 11, pp. 141-150.

Tests of two pre-tensioned unanchored beams with the steel on the tension side only. Both beams tested to failure; one failed by crushing, the other by breaking of wires. Measured: deflections, loads at cracking and the maximum loads. Data on materials and on dimensions of the specimen given.

1941

A20. Gueritte, T. J., "Further Data Concerning Prestressed Concrete", Journal, Institute of Civil Engineers, (London), 1941, Vol. 16, Nos. 6-8, pp. 91-136, 517-549.

Report of the tests of three prestressed concrete beams. Testing techniques, data on materials, and the test results are given. One beam is the same as reported by Opperman in 1940, the two others were built and tested in Southhall, England. The last two beams were identical, one was tested shortly after casting, the other one year later. Most of the test data and comparisons with theory made for stresses before first cracking. Ultimate loads are given. Interesting discussions by a large number of discussors.

A21. Roll, F., "Beitrag zur Wirkung einer Vorspannung auf die Korrosion von Eisen", Metallwirtschaft (Berlin), 1941, Vol. 20, No. 46, pp. 1115-1119.

Investigation of the effect of prestressing on rusting of various steels. Prestressing music wire; rusting increases somewhat with prestressing force, tensile strength is unaffected by rusting, ultimate elongation affected very considerably.

1942

A22. Bolomey, J., "Deformations elastiques, plastiques et de retrait de quelques betons", Bulletin Technique de la Suisse Romande (Lausanne), 1942, Vol. 68, No. 15, pp. 169-173.

A report of an experimental investigation conducted for the purpose of determining the effect of

1. prestress
2. length of hardening time at application of prestress
3. properties of concrete

on the magnitude of elastic and plastic deformations and on shrinkage of concrete. The results are presented in form of tables and graphs.

A23. Evans, R. H., "Relative Merits of Wire and Bar Reinforcement in Prestressed Concrete Beams", Journal, Institute of Civil Engineers, (London), 1942, Vol. 17, No. 4, pp. 315-329.

Tests were made to compare relative merits of wire and bar reinforcement. Tests were carried out on beams of 10-ft. span and various

magnitudes of initial prestressing. Central deflection and compressive and tensile strains were recorded. Because of larger losses of prestress, the cracking load of the beams with bars was much lower than that of beams prestressed with wires. It is also shown stresses in the steel and concrete as well as deflections are considerably higher for unbonded than for bonded beams.

A24. Evans, R. H.; Wilson, G., "Influence of Prestressing Reinforced Concrete Beams in Their Resistance to Shear", The Structural Engineer (London), 1942, Vol. 20, No. 8, pp. 109-122.

Tests were made on beams of varying length to determine (1) the effect of horizontal prestress on the diagonal tension cracking loads, (2) the effect of prestressing vertical stirrups on diagonal tension cracking loads for beams without horizontal prestress, (3) the loss of initial prestress in horizontal and stirrup reinforcement. Information on the test beams and procedures incomplete. Test results given in form of graphs and tables. Mautner's discussion in No. 12, pp. 297-299 is concerned with the very small amount of prestress used in these tests (22000 to 54000 psi.).

1943

A25. Bolomey, J., "Contribution a l'étude du béton précontraint", Bulletin Technique de la Suisse Romande (Lausanne), 1943, Vol. 69, Nos. 8, 9, 12, pp. 89-95, 101-109, 137-146.

A series of tests of pull-out specimens and prestressed beams. All beams pre-tensioned, of rectangular cross-section, prestressed with high-strength steel of diameter varying from 1 to 3 mm. First part devoted to studies of bond, second to flexural tests The following test data are given: measured steel and concrete stresses, deflections at various loads, cracking loads and ultimate loads.

A26. Freyssinet, E., " L'evolution future des proprietes des materiaux", Travaux (Paris), 1943, Vol. 27, No. 119, pp. 179-183

Freyssinet reviews briefly his work in prestressed concrete explaining what prestress concrete is and why high strength materials are desirable. He explains his theory of concrete hardening and how to attain high strength concretes.

A27. Panchaud, F., "Quelques aspects du calcul des ouvages en beton precontraint", Bulletin Technique de la Suisse Romande (Lausanne), 1943, Vol. 69, Nos. 22-23, pp. 285-293, 302-304.

The paper starts with general discussion of prestressed concrete. The following topics are then discussed in detail: amount and position of prestressing force, shrinkage and creep, variation of the steel stress under the load, allowable stresses, factor of safety against cracking and effect of shearing stressed. Second part of this paper deals with tests and descriptions of existing structures. Tests of 4 beams are described (with and without special anchorage). Given: dimensions, amount of prestress, and cracking and ultimate loads.

A28. Ross, A. D., "Creep and Shrinkage in Plain, Reinforced and Prestressed Concrete". "A General Method of Calculation", Journal, Institute of Civil Engineers, (London), 1943, Vol. 21, No. 1, pp. 38-57.

The author presents a method for calculating creep and shrinkage most of which have not been verified by tests. The formulas are somewhat cumbersome; some cases the author presents tabulated solutions.

A29. Volterra, E., "On the Deformation of Reinforced Concrete Structures and on the Calculation of Prestressed Reinforced Beams", Structural Engineer (London), 1943, Vol. 21, No. 4, pp. 123-138.

Derivation of equations for calculation of deformation of prestressed concrete beams both before and after cracking. Formulas substantiated with test results obtained some years earlier in Zurich.

1944

A30. Lossier, H., "Les ciments expansif et leurs applications autocontrainte du béton", Génie Civil, 1944, Vol. 121, Nos. 8-9, pp. 61-65, 69-71.

In this paper the author explains the principles of prestressed concrete and presents his own method of prestressing by use of expanding cements. Description of the tests conducted on expanding cements. Properties of expanding cements given in form of graphs. This article is similar to Lossier's paper "Cements with Controlled Expansion ...." in Structural Engineering, 1946-47.

A31. Rao, K. L., "Prestressed beams under Direct Bending and Sustained Loading", Structural Engineer (London), 1944, Vol. 22, No. 10, pp 425-454.

Tests were conducted on several small-size beams to determine the effects of prestressing. Load-deflection curves and loss of prestress with time are given. Concrete and steel strain are plotted vs. time. Both beam with and without bond were investigated. Ultimate loads and modes of failure are not given.

A32. - - - , "Compacted Reinforced Column Has Great Strength", Concrete, (Chicago), 1944, Vol. 52, No. 10, p. 40.

This test was conducted by Professor Maney. Column is constructed by placing a thin metal lining inside a spiral of steel wire and filling this with a specially compacted concrete. Water cement ratio was 1 gal. per sack of cement. One test unit withstood 83,000 psi. The purpose of the tests was to find materials to substitute for steel.

1945

A33. Lebelle, P., "Coefficients de sécurité des pieces fléchies en béton précontraint. Cas particulier des poutres a fils adhérents tendus avant bétonnage," Institut Technique du Batiment et des Travaux Publics, Circulaire Serie J, No. 5, 1945 (Paris).

The results of the tests are preceeded by a discussion of factor of safety. The tests were conducted on an isolated I-beam, on 3 similar beams with tile fillers between the beams and one other isolated beam with 10 percent lower prestress, tests in shear on beam as above, static and dynamic tests of bond.

1946

A34. Bjuggren, U., "Den armerade betongens verkningssät i sprickstadiet vid böjning," (The behavior of reinforced concrete during cracking in bending), Betong (Stockholm), 1946, Vol. 31, No. 3, pp 182-211.

This paper contains some results of tests of rectangular and I-section prestressed concrete beams. Very few data given.

A35. Hahn, L., "Application du cercle de Mohr calculs des contraintes et armatures des parois en béton et béton precontraint", Travaux (Paris), 1946, Vol. 30, No. 135, pp. 27-34 and No. 136, pp. 70-78.

Solution of state of stress at a point by use of Mohr's circle. Use of Mohr's circle for determining the necessary amount of prestress.

A36. Lossier, H., "Cements with Controlled Expansions and Their Application to Prestressed Concrete", Structural Engineer (London), 1946, Vol. 24, No. 24, pp. 505-534.

Description of the composition, behavior and use of the expansive cements for prestressing of concrete beams. The author admits that for prestressing of beams the expansive cement is not yet as effective as various mechanical ways of prestressing. Paper is discussed in ditto 1947 Vol. 25, p. 142.

A37. Ros, M. R., "Vorgespannter Beton", Swiss Federal Material Testing Laboratory, (EMPA), Report No. 155, Zurich 1946.

This report consists of three parts: investigation of materials for prestressed concrete beams, investigation of bond between the prestressing wire and the concrete, and investigation of prestressed concrete beams in flexure.

Materials: effect of steam curing and vibration on the compressive strength of concrete, tensile vs. compressive strength, effect of prestressing of tensile compressive strength and endurance limit of concrete, creep of concrete also plastic recovery - all for high strength

concrete; tests of various types of wires, measured: tensile strength, elastic limit, limit of proportionality, contraction in area at the ultimate, ultimate elongation, endurance limit and fatigue strength. Bond: tests of both pull-out and beam specimens with various types of wire, both prestressed and unstressed. Both static and dynamic tests.

Beams: static and dynamic tests of both I- and rectangular beams, all wires pretensioned, no end anchorages used. Cracking loads, ultimate loads and deflections given for 7 I-beams together with modes of failure. The report includes large number of load-strain and load-deflection curves and pictures of several beams after failure.

A38. Staley, H. R.; Peabody, D., "Shrinkage and Plastic Flow of Prestressed Concrete", Proceedings, American Concrete Institute, 1946, Vol. 43, No. 3, pp. 229-243.

Tests of bars 4 x 4 x 24 in. made of either concrete or gunite conducted at MIT. Prestress load sustained for 400 days. Results reported in forms of figures and tables.

1947

A39. Baker, A. L. L., "Shear and Deflection in Prestressed Reinforced Concrete Beams", Concrete and Constructional Engineering (London), 1947, Vol. 42, No. 9, pp. 267-269.

Discussion of shears and deflections of prestressed concrete beams limited to the range of applicability of elastic formulas. The author suggests, that diagonal tension cracks should not take place in a prestressed concrete beams, but the formation cannot be prevented by conventional shear reinforcement.

A40 Campus, F., "La limite de fluage des aciers á la températa-ture ordinaire", Revue Universalle des Mines de la Metallurgie des Travaux Publics (Paris), 1947, 9th Series, Vol. 3, No. 12, pp. 595-605.

Report of tests of creep of steel at constant normal temperature under constant load and under constant deformation. Experimental techniques explained and the results of the tests discussed.

A41 Guyon, Y., "Poutres en béton précontraint de section uniforme a cables relevés", Institut Technique du Batiment et de Travaux Publics Circulaire Serie J, No. 9, Paris, 1947.

This paper deals with beams prestressed by several cables, some of which may be curved up to resist diagonal tension. The state of stress in the beam with curved-up cables is explained.

A42 Lossier, H. "Les ciments sans retrait et a expansion", Revue Universelle des Mines (Paris), 1947, Vol. 13, No. 4, pp. 166-169.

This one of the first Lossier's articles on expanding cements

A43. Magnel, G., "Essais de quelques poutres en beton precontraint", La Technique de Travaux (Paris), 1947, Vol. 23, Nos. 3-4, pp. 87-100.

Tests of 11 beam of I and T sections. All flexural tests with good description of materials and their properties. Deflections, cracking loads and ultimate loads calculated and compared with measured values. Both post-tensioned and pre-tensioned beams. Most of the beams failed by breaking of steel. These tests are reported also in Magnel's book.

A44. Wets, G.; Paduart, A., "Recherches experimentales sur certaines proprietes mecaniques des aciers speciaux utilises en beton precontraint", La Technique des Travaux (Paris), 1947, Vol. 123, Nos. 7-8, pp. 213-219.

Report of the tests of creep at ordinary temperatures and endurance tests under high tensions. The discussions of the test procedure and test results are good.

A45. - - -, "Comparison of Partially and Fully Prestressed Concrete Beams", Concrete and Constructional Engineers, (London), 1947, Vol. 42, No. 1, pp. 11-15.

Short report of tests of 8 T-beams made by Magnel. All beams had 24 wires of .197 in. diameter, all but one grouted. In one of the beams only half of the wires were prestressed. Total reinforcement was about 0.2 percent f' > 6000 psi. All failures by breaking of the wires. (See also C. Magnel text book, "Prestressed Concrete" published by Concrete Publications Limited, London, pp. 115-124.

A46. - - -, "Prestressed Reinforced Concrete Sleepers Tested as Simply Supported Beams," Concrete and Constructional Engineers, (London) 1947, Vol. 42, No.s 4-5, pp. 123-132, 155-161.

This report prepared by P. W. Abeles describes static tests of 13 prestressed concrete sleepers made by L. N. E. R. Five of the beams were in service for 2 1/2 years prior to testing (subjected to about 4×10^6 repetitions of load). The test data are reported in the form of load-deflection and load-width of crack curves for few specimens. Cracking and ultimate loads are tabulated for all specimens. The cracking load is compared with corresponding computed tensile stresses - which are rather high. The ultimate loads are discussed. Data on materials incomplete.

A47. - - -, "The Yield Stress and Creep of Steel", Concrete and Constructional Engineers, (London), 1947, Vol. 42, No. 4, pp. 105-106.

Creep of commercially obtainable wire (in Belgium) when under a constant stress of 75 percent of the yield stress was found to be very great during the first hour and was still substantial during the first 20 hours, but subsequently slackened and attained 90 percent or so of the final value in about 2 months. The final value appears to be about 16 percent of the original deformation. If an initial stress of 60 percent of ultimate stress is maintained for 2 min. and then reduced

to about 80 percent of the yield, the final apparent creep is much reduced due to the over fact that in the initial 2 min. under the higher stress the same amount of creep occurs as during first 4 or 5 hours under a constant but lower stress. These results are from tests by Magnel.

1948

A48. Anderegg, F. O., "What Will Be Prestress Loss Due to Creep?", Proceedings American Concrete Institute, 1948, Vol. 45, No. 1, p. 86. Letters from Readers Sections.

Author points out that various statements regarding creep in concrete and prestressing wire are conflicting.

A49. Billig, K., "Research Work and Test Production of Prestressed Concrete Units at the Field Test Unit, Ministry of Works," London, Int. Assoc. Bridge and Struc. Eng., Third Congress, Final Report, Liége, 1948, pp. 367-372.

Short list of development work done by the Field Test Unit in 1947-48. This work was essentially in two groups: anchorages and bond, experimental manufacture of various structural units. Few conclusions given.

A50. Bjuggren, U., "What Will Be Prestress Loss Due to Creep?" Proceedings, American Concrete Institute, 1948, Vol. 45, No. 4, p. 343. Letters from Readers Section.

Answer to Andregg's question in ACI Proceedings, 1948, No. 1. According to Swedish experiences the bond depends on:

1. Quality of concrete
2. Compaction of concrete
3. Strength at release
4. Type of curing before and after release
5. Amount of prestress
6. Diameter of wire
7. Surface properties of wires

A51 Dawance, M. G., "Une nouvelle méthode pour l'etude de la relaxation des fils d'acier", Annales de L'Institute Technique du Batiment et des Travaux Publics (Paris), New Series No 9, 1948.

Report of tests of creep of 5mm prestressing wire. Stress-time curves are given for various amounts of prestress and for wires of various lengths. Strain in the wire was measured by frequency of vibration method

A52 Friedrich, E., "Neuere Erkenntnisse über vorgespannter Beton", Int. Assoc. Bridge and Struc. Eng., Third Congress, Final Report, Liége, 1948, pp. 359-366

Short report of tests of 14 types of prestressed concrete - beams, 3 beams of each type. Percentage of reinforcement, the only variable, varied from 0.128 to 0.814 percent total, where 0.086 to 0.643 percent was tensile reinforcement. Average loads for each type at first cracking and ultimate reported and compared with theoretical values. Theoretical values computed as for beams subject to combined flexure and direct compression. Good agreement at failure, computed values too low at cracking. Question of losses in prestress discussed at some length.

A53. Lossier, H., "Les ciments expansifs et l'autocontrainte du beton", Int. Assoc. Bridge and Struct. Eng., Third Congress, Final Report, Liege, 1948, pp. 335-344.

The author explains the behavior of expanding cements their composition and properties. Gives many examples of use in structures, emphasizing the ability of expanding cement to act as a prestressing agent.

A54. Magnel, G., "Creep of Steel and Concrete in Relation to Prestressed Concrete", Proceedings, American Concrete Institute, 1948, Vol. 44, No. 6, pp. 485-500.

Tests on creep of steel and on shrinkage and creep of concrete. Tests on steel were carried out with Belgian wire. Complete information and interpretation of results are given.

A55. Mautner, K. W., "Tests on Precast Prestressed Concrete Frams in Multistory Buildings", Int. Assoc. Bridge and Struct. Eng., Third Congress, Final Report, Liege, 1948, pp. 388-392.

Description of tests of frames composed of prismatic beams and columns assembled and prestressed at the site. Tests made by the Building Research Station. Freyssinet system of prestressing used

A56. Paduart, A., "Ponts de grande portee en béton précontraint realises en belgique", Int. Assoc. Bridge and Struct. Eng., Third Congress, Preliminary Publication, Liége, 1948, pp. 325-332.

Description of two girders, one for a footbridge the other built for testing purposes. Tested first slightly above the cracking load (which was more than twice the design load) with a static load; a dynamic test followed.

1949

A57 Armstrong, W. E. I., "Bond in Prestressed Concrete", Journal, Institute of Civil Engineers, (London), 1949, Vol. 33, No 1 pp. 19-40.

Pull-out and beam tests of prestressing wire. Both pretensioned and unstressed wire investigated. Wires with ripples employed, some with cleaned, some with rusted finish. Testing procedure, test specimens and test results are given.

A58. Bowman, W., "Full-Size Prestressed Girder Tested", Engineering News Record, November 3, 1949, Vol. 143, No. 18, pp 18-19.

Description of Walnut Lane Bridge girder test. Design load, ultimate load and deflections given. Describes appearance of cracks.

A59. Magnel, G., "Prototype Prestressed Beam Justifies Walnut Lane Bridge Design", Journal, American Concrete Institute, 1949, Vol. 47, No. 4, pp. 301-316.

Description of the test of Walnut Lane Bridge girder.

A60. Marshall, G., "End Anchorage and Bond Stresses in Prestressed Concrete", Magazine of Concrete Research, 1949, Vol. 1, No. 3, pp. 123-127.

Tests of bond for 0.08 and 0.2" diameter wire. All tests were made with columns made of concrete with $f'_{cu} =$ 11,500 psi. All specimens were pre-tensioned. The test results are given in several graphs and compared with theoretical values. The work was carried out at Leed's University.

A61. Soete, W.; Vancrombrugge, R., "La résistance à la fatigue ondulée des fils utilisés en béton précontraint", Annales des Travaux Publics de Belgique (Bruxelles), 1949, Vol. 102, No. 5, pp. 513-534.

Fatigue tests of cold drawn prestressing wire are described and supplemented by the results of fatigue tests of cold drawn wire made by others. The authors state that galvanizing and decarburization seem to reduce the fatigue strength and the thermal treatment seems to improve this resistance.

Tests were made on 5 and 7 mm. wires anchored by 5 different anchorages, all of them of the frictional wedge types. All tests were made in repeated tension with min load 75 kg/mm^2 and maximum varying from 85 to 105 kg/mm^2, while the static ultimate was about 150 kg/mm^2. Fluctuation of load from 75 to 85 did not cause failure even at 2000000 repetitions, from 75 to 105 caused failure in nearly all specimens below 1000000 repetitions. Some of the failures occurred in grips, others outside the anchorage. The testing set up is described in detail. Bibliography of previous work on the subject is attached.

See also CACA Library Translation Cj. 25, 1951.

A62. - - -, "Philadelphia Tests First Prestressed Girder", The American City, (New York), 1949, Vol. 64, No. 12, pp. 123-125.

This article merely describes the girder being tested for Walnut Lane Bridge and shows pictures of it during the test. No test date is given.

A63. - - -, "Testing Long Prestressed Concrete Girder", Concrete, (Chicago), 1949, Vol. 57, No. 12, pp. 3-6.

A64. - - -, "Tests of Prestressed Concrete Beams", Concrete and Constructional Engineering (London), 1949, Vol. 44, No. 2, pp. 52-53.

Test of two beams. Calculated load to cause comp. failure was 8.3 tons; for tension failure 9.4 tons. Cracks occurred after beam was loaded and unloaded 3 times to value of 6 tons. At 7 1/2 tons, defl. was 2"; deflection returned to 0.08 in. with no load. Beam failed by compression and shear at 8 1/4 tons. The second beam had additional unstressed wires; cracks occurred at 7 tons; at 9 tons, the deflection was 1 1/2"; the load of 9 tons was reapplied 3 times, cracks becoming visible at 4 tons. Bonded prest. both beams.

1950

A65. Abeles, P. W., "Balkenversuche mit britischen vorgespannten Betonschwellen und eine neue Art von Strassenbrücken uber Bahnen in England", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 2, pp. 36-39.

The author reports tests of railroad ties made in England. Deflection diagrams are given. I-beam bridge composed of prestressed concrete I-beams laid adjacent to each other are also discussed. This material is similar to that in Abeles' book.

A66. Abeles, P. W.; Hockley, C. H., "Small Scale Demonstration Tests in Prestressed Concrete Beams", Structural Engineer, (London), 1950, Vol. 28, No. 6, pp. 146-153.

Fourteen prestressed beams of various cross sections were tested for demonstration purposes. Part of the beams was pre-tensioned, part post-tensioned. Load-deflection curves, cracking loads and modes of failure are given, but the properties of materials are not reported.

A67. Baar, G., "Tests on Prestressed Concrete Beams in Holland", Cement (Amsterdam), 1950, Nos. 13-14. English Translation by Cement and Concrete Association (London), Translation cj. 21, 1950.

Performance tests made on one T-beam picked at random from a pile of 150 beams made for construction of office buildings at Heerlen. Post-tensioned beam, Magnel system. Static loading over the cracking load, impact test, heating test (865°C) loading to rupture. Only deflections measured. Cracking at 2 1/2 L.L. Final Failure by crushing of the compression zone at 3 (D.L.+L.L.)

A68. Campus, F., "Le béton précontraint", Annales des Travaux Publics de Belgique (Bruxelles), 1950, Vol. 103, Nos. 1-2, pp 19-49, 295-332.

This paper is a report of static tests of four beams (one pretensioned- left-over from German fortifications, three post-tensioned) of T, rectangular and U sections, static tests of tubes, dynamic tests of railroad ties and pressure tests of pipes. Three of

the beams with static loading failed by crushing of concrete, one by rupture of steel. Ties tested with repeated loading failed in bond when pretensioned and by rupture of wires when with end anchorages.

A69. Dehan, E.; Louis, H., "Mesure des efforts et de leur variation dans les fils accessibles des ouvrages en béton précontraint", Annales des Travaux Publics de Belgique (Bruxelles), 1950, Vol. 103, No. 2, pp. 202-260.

Detail description of instruments used to measure strains in prestressing steel of the Sclayn Bridge in Belgium. Strain in "cables" were measured with the aid of tube dynamometers and strains in individual wires by vibration method.

A70. Fornerod, M., "Load and Destruction Test of 160 ft. Girder Designed for First Prestressed Concrete Bridge in U.S.A.", Int. Assoc. Bridge and Struct. Eng., Publications, Vol. 10, Zurich, 1950, pp. 11-35.

Best paper on the test of the Walnut Lane Bridge girder.

A71. Fuchs, D., "Versuche mit Spannbeton-Verbundtragern", Der Bauingenieur (Berlin), 1950, Vol. 25, No. 8, pp. 289-294.

Tests conducted on a composite steel I-beam, prestressed concrete slab floor systems are described. Test procedures and results are given. Properties of materials are given.

A72. Lazard, A., "Nouveau phénomenes de plastification concernant les I en acier doux et le beton précontraint découverts grâce aux extensometres a résistance électrique", Travaux (Paris), 1950, Vol. 34, pp. 301-314, No. 187.

A part of this paper is concerned with prestressed concrete; it gives measurements of strain made on beams with the aid of electric strain gages.

A73. Masterman, O. J., "Prestressed Concrete Developments at the Field Test Unit. Thatched Barn", Struct. Engineer (London), 1950, Vol. 28, No. 10, pp. 246-264.

Several hundred small joists and few large members have been tested at the Field Test Unit and the results of these tests are given. The results are given for groups of specimens, not for individual specimens. Special attention was paid to anchorages and to attaining equal stress in the wires. Both bonded and unbonded types of beams were tested. Joists were tested individually and in groups supporting one slab

A74. Mörsch, E., "Die Ermittlung des Bruchmoments von Spannbetonbalken", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 7, pp. 149-157.

A graphical method for finding the neutral axis at the ulti-

for steel and concrete. In the second part of the article Mörsch reports the results of tests of 9 concentrically and two excentrically loaded plain concrete prisms. These tests were designed by Mörsch in order to investigate whether there is any "plastic flow of concrete at loads approaching ultimate. Mörsch concludes that there is no such thing; that the stress-strain diagram for concrete in concentric and excentric loading is about the same, approximately parabolic in shape. Max measured strain about 0.3 percent in 50 cm.

A75. Ritter, M.; Lardy, P., "Vorgespannter Beton," Mitteilungen aus dem Institute für Baustatik an det ETH, First Edition, Zurich, 1946, Second Edition, Zurich 1950 (Verlag Leemann).

Short historical summary and summary of present knowledge. Theory for computing stresses, cracking load and the ultimate capacity. Investigations at Lausanne, Schinznach, Zurich (EMPA). Recommendations for design. Swiss construction examples.

The theory and investigations limited to pre-tensioned unanchored beams.

Investigations at Lausanne (Bolomey 1942, 1943) and at Zurich (Ros, 1946) only summarized. Investigation at Schinzbach reported in more detail - tests of rectangular beams with varying amounts of prestress and of reinforcement. Both long and short time tests. Principal test results: ultimate capacity independent of prestress, behavior to first cracking practically elastic, creep depends on the age at time of application of prestress, creep practically completed after two years. The description of Swiss construction includes some tests of individual beams and study of creep of both steel and concrete.

The second edition includes all material from the first one; the chapter on construction examples somewhat enlarged in the second edition.

A76. Ros, M., "Die material technischen Grundlagen und Probleme des Eisenbetons im Hinblick auf die Zukünftige Gestaltung der Stahlbeton-Bauweise", Swiss Federal Materials Testing Laboratory (EMPA), Report No. 162, Zurich 1950, pp 231-245.

Short summary of the results of the Swiss test reported in the EMPA Report No. 155 by Ros in 1946. Recommendations for design included same as in Report No. 155.

A77. Ross, A. D., "The Loss of Prestress in Concrete" Civil Engineering and Public Works Review (London), 1950, Vol. 45, No. 527, pp 307-309.

The author discusses the need for information regarding the creep. Then he gives charts relating creep, w/c ratio and the age of concrete. Gives some equations for prediction of creep.

A78. Rüsch, H., "Bruchlast und Bruchsicherheitsnachweis bei Biegungsbeanspruchung von Stahlbeton unter besonderer Berücksichtigung der Vorspannung", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 9, pp. 215-220.

Discussion and development of formulas for ultimate load and so called critical load (max. useful load) for flexural reinforced and prestressed concrete members. The formulas are the same for both materials. They are based on Bernoulli's hypothesis, limiting ultimate concrete strain and concrete stress block characterized by two coefficients. Critical load is further limited by limiting steel strains; lower limit requires that the crack at failure be visible (warning), upper limit requires that the width of crack does not make the structure unusuable.

A79. Schwarz, R., "Vorspannungsverluste und Durchbeigungen an einer vorgespannten Stahlbeton Brücke infolge Kriechen und Schwinden", Der Bauingenieur (Berlin), 1950, Vol. 25, No. 1, pp. 1-8.

Detail report of the results of field measurements made on a prestressed concrete bridge in Germany (Dischinger method of prestressing) for the purpose of determining the losses in prestressing. Total losses were rather high - about 25 percent.

A80. - - -, "A Test of Prestressed Concrete Railway Bridge" Concrete and Constructional Engineers, (London), 1950, Vol. 45, No. 8, pp. 296-299.

A girder 13 by 27 in. by 43'-6" long was tested to destruction. Properties of materials are given. Measured deflection and calculated stresses are given. The occurrence and size of cracks is given. A discussion of estimated losses of prestress is given. Test results substantiated design procedure.

A81. - - -, "Concrete Prestressed by Alloy Bars", Engineering News Record, June 22, 1950, Vol. 144, No. 22, p. 41.

Description of the properties of a newly developed alloy steel bar. Bar developed in England.

A82. - - -, "Steel-alloy Bars used in Prestressed Concrete", Concrete and Constructional Engineers, (London), 1950, Vol. 45, No. 4, pp. 127-128.

This article is a description of a high-strength steel bar available in diameters up to 1 1/8 in. Bar has threaded ends, strength of 70 t/in^2, no marked yield point.

A83. - - -, "20 Ton Prestressed Trestle Slab Tested To Failure", Concrete, (Chicago), 1950, Vol. 58, No. 11, pp. 3-4.

A brief explanation of the test on trestle slab made by PCA. A description of the slab and the prestressing cables is given but no significant test results.

1951

A84. Abeles, P. W., "Breaking Tests on Three Full Size Prestressed Concrete Bridge Beams", Structural Engineer (London), 1951, Vol. 29, No. 5, pp. 149-160.

Description of tests to destruction of three beams, two of which had only part of the wires prestressed. Load-deflection curves are given, and the behavior of beams during testing described. The information on properties of materials is incomplete.

A85. Abeles, P. W., "How Much Prestress?", Engineering News Record, July 5, 1951, Vol. 147, No. 1, pp. 32-33.

Discussion of the effect of the amount of prestress on the load-deflection characteristics of prestressed concrete beams based on the assumption of flexural failure.

A86. Abeles, P. W., "Prestressed Beams with Bond", Engineering News Record, April 12, 1951, Vol. 146, No. 15, pp. 42-43.

Discussion of the advantages of the presence of bond between the wires and the concrete and of the behavior of under- and over-reinforced beams at cracking and at failure.

A87. Anderson, A. R., "Field Testing of Prestressed Concrete Structures", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 215-220.

Tests on large prestressed concrete beams such as the 160 ft. Walnut Lane Bridge Girder and the 30 ft. beam for small highway bridge for Concrete Products Corporation of America are discussed. Technique of testing more than results of tests is discussed.

A88. Ashton, L. A., "The Fire Resistance of Prestressed Concrete Floors", Civil Engineering and Public Works Review (London), 1951, Vol. 46, No. 545, pp. 843-845; No. 546, pp. 940-943.

The existing British fire resistant specifications are discussed and suggestions are given which would improve the code. Tests were made on seven different types of floors with prestressed concrete beams and joints. Test results are given and discussed. Test program is sponsored by Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices Committee.

A89. Baker, A. L. L., "Recent Research in Reinforced Concrete and Its Application to Design", Journal, Institute of Civil Engineers, (London), 1951, Vol. 35, No. 4, pp. 262-329.

A theoretical treatment of various topics pertaining to the design of reinforced concrete structures both conventional and prestressed. The sections on the ultimate strength of rectangular

sections, both prestressed and ordinary, and on plastic deformations are of interest. Both bonded and unbonded types are treated. Some test data are cited, but the author states that final results will be given in an addendum to the paper.

A 90. Baker, A. L. L., "The Ultimate Strength in Bending of Prestressed Concrete Beams," The Reinforced Concrete Review, (London), 1951, Vol. 2, No. 6, pp. 343-373.

The same material as in Baker's paper published in the Journal of Institute of Civil Engineers, 1951, No. 4, under the title "Recent Research in Reinforced Concrete and its Application to Design".

A 91. Blanks, R. F., "Concrete for Prestressing", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 136-149

This paper discusses the properties of plain concrete and the materials used in concrete with respect to their relationship on strength.

A 92. Caquot, "Precontrainte et fluage", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 235-237.

This article describes methods of calculating creep of steel and concrete in prestressed concrete beams. Methods for partial elimination of creep are discussed.

A 93. Collins, A. R., "Research and the Development of Prestressed Concrete," Building Research Congress, 1951, Division 1, pp. 68-73, (England).

This paper is primarily concerned with research in England. A list of investigations conducted at various institutions in England is included.

A 94. Cooley, E. H., "Progress in Prestressed Concrete Research", Magazine of Concrete Research (London), 1951, No. 7, pp. 31-36.

This is a good paper on progress of prestressed concrete research in England. It lists what work has been done, is being done or planned.

A95. Crepps, R. B., "Glass Fibers as Tensioning Element in Prestressed Concrete", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 228-230.

This paper outlines the feasability of using glass fibers as the prestressing element in prestressed concrete with consideration of the advantages and disadvantages.

A96. Dardanelli, G., "Activité du Centre d Etude de Turin dans le domain expérimental", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 206-207

Outline of tests of prestressing wires and of prestressed beams conducted at Turin, Italy. Test results not given.

A97. Deutsch, E. "Probebelastung eines unterspannten Betonträgers", Beton-und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 3, pp. 56-59.

Two beams prestressed with steel underslung (Dischinger method) were tested. Load vs. deflection curves are drawn. Tests are described and results discussed.

A98. Evans, R. H., "Research and Developments in Prestressing", Journal, Institute of Civil Engineers, (London), 1951, Vol. 35, No. 4, pp. 231-261.

Tests of bond on pretensioned beams, investigation of steam and pressure curing, load tests of pretensioned beams. A table is given which includes ultimate loads and cracking load for 19 beams. The relative merits of partial and complete prestressing are discussed and few historical notes given.

A99. Franco-Levi, "Nouvelles recherches sur les constructions précontraintes", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 238-239.

Discussion of the prestressed concrete research carried on in Italy (creep, shrinkage, etc.) and of the problems encountered.

A100. Godfrey, H. J., "Steel Wire for Prestressed Concrete", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 150-166

Mr. Godfrey discusses the properties of wire manufactured by John A. Roebling s Sons Company, for use in prestressed concrete. Mr. Eney, and Mr. Loewer, of Lehigh University contribute to the discussion by reporting briefly on tests conducted on the wire as it was used in beams. Mr. Everling, director of research of American Steel and Wire, contributes further to the discussion of the properties of wire.

A101. Haas, A., "Essais de charge sur poutres en béton précontraint", Travaux, (Paris), 1951, Vol. 35, No. 196, pp. 204-206.

This is a discussion of some tests of large prestressed concrete beams conducted in Holland. Beams of the same type were used in an actual structure. No specific numerical test data are given, but the behavior is discussed and the factor of safety is given. Attention is called to grouting, the failure of which might results in a lower factor of safety.

A102. Habel, A., "Traglastprobleme des Stahlbetonbaues", Beton-und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 1, pp. 6-10.

This paper is concerned with the ultimate load on concrete columns axially and eccentrically loaded, prestressed and non-prestressed.

A103. Jäniche, W., "Neue Erkenntnisse über Festigkeitseigenschaften und Beanspruchbarkeiten von Spannbetonstählen", Beton-und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 7, pp. 161-165; No. 8, pp. 184-187.

This paper deals with the properties of steel used for prestressing concrete in Germany

A104. Janney, J. R., "Analysis of Test of Full Scale Prestressed Concrete Railroad Trestle Slab", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 241-243.

Future tests planned by the Portland Cement Association are briefly discussed. The test on a full-sized railroad trestle is discussed and explained. A few results of this test are shown.

A105. Kennedy, H. L., "High Strength Concrete", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 126-135.

This paper deals with factors which affect the concrete strength and explains conditions for attaining high strength concrete.

A106. Lee, D. H., "High Tensile Alloy Steel Bars for Prestressed Concrete", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 167-177.

The Lee-McCall steel rod for use in prestressed concrete work is described. The ultimate strength is 157,000 psi; the creep is negligible; the ends are threaded for coupling together and anchorage; full strength of rod can be developed. Author claims a savings can be realized in use of this bar in spite of its lower strength than wires.

A107. Lee, D. H., "High Tensile Alloy Steel Bars for Prestressed Concrete," Civil Engineering and Public Works Review, (London), 1951, Vol. 46, No. 543, pp. 668-671; No. 544, pp. 770-771.

This paper appeared originally at the First U. S. Conference on Prestressed Concrete at MIT, 1951. Lee's high-alloy steel bar with ultimate strength of 70 tons/sq. in. and low creep characteristics is described. Method of prestressing by coupling the rods together and stretching with special jack is described.

A108. Magnel, G., "Concrete Good Enough?" Engineering News Record, May 17, 1951, Vol. 146, No. 20, p. 44., Reader Comment Section.

Advocacy of low slump concrete for prestressing work.

A109. Meissner, H. S., "Would Glass Fibres Stand Up?" Engineering News Record, June 28, 1951, Vol. 126, No. 26, p. 44., Reader Comment Section.

Discussion of Rubinski's suggestion of the use of glass fibres for prestressing. Meissner points out the danger of alkali reaction.

A110. Munger, H. H., "Glass and Concrete Reaction", Engineering News Record, June 21, 1951, Vol. 146, No. 25, p. 47., Reader Comment Section.

Discussion of Rubinski's suggestion of the use of glass fibres for prestressing. Munger warns of violent alkali reaction of glass when in contact with portland cement.

A111. Prentis, J. M., "The Distribution of Concrete Stress in Reinforced and Prestressed Concrete Beams when Tested to Destruction by Pure Bending Moment", Magazine of Concrete Research (London), 1951, Vol. 2, No. 5, pp. 73-77.

It is shown in this paper that the stress-strain curve for reinforced concrete subject to bending may be determined from tests solely on the basis of the conditions of statics and of the following assumptions:

(1) Linear distribution of strain
(2) Existence of definite stress-strain relationship $f = E(e)$ independent of both the time and location.

Equations for compressive and tensile stresses are derived in terms of external forces acting on the section considered, the strains on the top and bottom of the section and the section properties. A check on the solution is provided by $f_t \equiv 0$ after first cracking.

The equations are applicable to ordinary reinforced concrete beams and to prestressed beam both with and without bond. Besides strains and the moment at the section considered also the force in the reinforcement must be known.

A112. Prot, "Le résistance du béton et la sécurité en béton précontraint", Travaux (Paris), 1951, Vol. 35, No. 196, pp 243-244.

Discussion of quality of materials and working stresses to be used for prestressed concrete.

A113. Ross, A. D., "Shrinkless and Creepless Concrete", Civil Engineering and Public Works Review (London), 1951, Vol. 46, No. 545, pp. 853-854.

The author gives a few test results which show that the shrinkage losses in post-tensioned prestressed concrete can be eliminated if before tensioning the concrete member is vacuum cured or cured to oven dryness. The member is prestressed upon cooling and instead of shrinking will actually expand due to atmospheric humidity. Only a few pilot tests were conducted--more are scheduled.

A114. Ross, A. D., "Tests of Prestressed Concrete Beams with Alloy Steel Bars", Magazine of Concrete Research (London), 1951, No. 7, pp. 9-18.

Five beams of various spans and cross section were prestressed with alloy steel bars (Lee's system). Beams were constructed and tested at the Field Test Unit. Properties of materials, method of measuring strains and test procedure are given. From test results ultimate loads, load-deflection and load-strain curves are given. All beams were post-tensioned and grouted. 2 of them assembled from smaller units, 3 cast monolithically.

A115. Rubinsky, I. A., "Glass Fiber being Studied", Engineering News Record, July 26, 1951, Vol. 247, No 4, p. 47., Reader Comment Section.

Answer to Meissner's comments (ENR June 28, 1951) on possible reaction between glass and the concrete in a concrete beam prestressed with glass fibres. Rubinsky remarks that IAR is conducting research at Princeton on use of glass fibres for prestressing.

A116. Ruble, E J., "Strain Measurements in a Prestressed Concrete Slab", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp 244-246.

This paper augments J R. Janneys paper (in the same publication), "Analysis of Test of Full Scale Prestressed Concrete Railroad Trestle Slab". It discusses in particular the strain measurements made on the full-size prestressed concrete trestle tested by Portland Cement Association with respect to how these strains were measured

A117 Siess, C. P., "Research in Prestressed Concrete", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 207-214.

This paper acknowledges the lag between practice and research in prestressed concrete. A discussion is made of the need of specifications, where they will come from and upon what will they be based. The variables affecting behavior of prestressed concrete beams; and proposed investigations into questions of flexure, shear, diagonal tension, bond, and properties of materials are discussed

A118. Steele, R. K.; Libby, J. R., "Preliminary Tests of Prestressed Concrete at the U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 231-240.

A rather inclusive series of planned tests on prestressed concrete are described. The initial tests on beams are described, but only a few results are given.

A119. - - -, "Impact Tests on Prestressed Concrete Fender Piles", Concrete and Constructional Engineering (London), 1951, Vol. 46, No. 3, pp. 89-91.

The material for this paper was taken from "The Application of Prestressed Concrete to Structural and Building Work in the Gas Industry" published by the Institution of Gas Engineers, with S. V. Gardner as author.

A performance test was conducted on prestressed concrete piles protecting a riverside of a loading crane way. Drop tests were made and records of damped oscilations, static and dynamic deflections were made.

A120. - - -, "Prestressed Concrete for Industrial Building Studied", Civil Engineering, 1951, Vol. 21, No. 9, p. 553.

Description of the tests of one 40 ft. and one 60 ft. girder designed by Freyssinet method and tested to destruction by the Austin Company in Euclid, Ohio. Only the most important data given.

A121. - - -, "Prestressed Concrete R. R. Trestle Slab", Concrete for Railways (Portland Cement Association), No. 44, 1951.

Description of the test of one railroad trestle slab of prestressed concrete. Slab prestressed with Roebling cables and tested to destruction. Design and construction are described in detail, section and material properties given and test procedure described. Some of the test data given.

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B-22, B-28, B-29, B-111, B-114, B-135, B-150, C-2, C-20, C-21, C-30,

D-14, D-23, D-40, D-67, D-70, D-90.

B. Construction.

1905-1935

B1. Lund, J. G. F., "Beschreibung der Konstruktion und Verwendung von Eisenbotonhohlblöcken armiert nach System Lund", Beton und Eisen (Berlin), 1905, Vol. 4, Nos. 6-7, pp. 143-145, 169-173.

Historically interesting proposal for making beams of concrete blocks connected by steel prestressed rods.

B2. Wuilleumier, B., "Bauten nach System Lund", Beton und Eisen (Berlin), 1906, Vol. 5, No. 9, pp. 227-229.

Description of few structures built according to the Lund System (see Lund, Beton und Eisen 1905).

B3. L'Heremite, R., "Machine de charge a haute puissance, pour essais de pieces de construction", Genie Civil, (Paris), 1935, Vol. 107, No. 2, pp. 44-45.

This article explains the construction and operation of a testing machine designed by Freyssinet. It is a compression machine built of prestressed concrete; its capacity is 2000 tons.

1936

B4. Coyne, M., "Application of Prestressing in Dams", Int. Assoc. Bridge and Struct. Eng., Second Congress, Final Report, Berlin 1936, pp. 706-713.

Anchoring of gravity dams with the aid of prestressed cables.

B5. Dischinger, F., "The Elimination of Bending Tensile Stresses in Reinforced Concrete Bridges", Int. Assoc. Bridge and Struct. Eng., Second Congress, Preliminary Publications, Berlin 1936 (publisher W. Ernst), pp. 759-781.

The author deals with a method of prestressing with cables outside the section. Examples of actual structures consisting of this type of hollow girder given.

B6. Kilgus, E. M., "Maste aus Eisenbeton mit verbesserter Ausnützung der Bewehrungeisen", Zement (Berlin), 1936, Vol. 25, No. 51, pp. 889-890.

Description of prestressing hollow concrete masts. Round bars with threaded ends are used for this purpose.

B7. Makcheeff, T., "Tensions préalables des armatures et moyens de les réaliser á peu de frais", Travaux (Paris), 1936, Vol. 20, No. 46, pp. 477-481.

This paper deals with a method of prestressing trussed members.

1937

B8. Boase, A. J., "Notes on Inspection of Structures in Europe", Proceedings, American Concrete Institute, 1937, Vol. 33, No. 5, pp. 521-540.

Brief description of prestressed piles used by Freyssinet to support a sinking building (pp. 521-526).

B9. Coyne, A., "The Construction of Large Modern Water Dams", Structural Engineer (London), 1937, Vol. 15, No. 2, pp. 70-84.

Large dams are prestressed vertically with cables anchored deep in subsoil. This method is used in France to strengthen existing dams.

B10. Wedler, "Neue Wege im Eisenbetonbau nach Freyssinet", Zentralblatt der Bauverwaltung (Berlin), 1937, Vol. 57, No. 20, pp. 506-509.

Description of various early uses of prestressed concrete.

1938

B11. Finsterwalder, U., "Eisenbetonträger mit selbsttatiger Vorspannung", Der Bauingenieur (Berlin), 1938, Vol. 19, Nos. 35-36, pp. 495-499.

Description of a prestressed concrete bridge prestressed by the Dischinger-Finsterwalder method and of a prestressed concrete truss.

B12. Finsterwalder, U., "Eisenbetonträger mit Vorspannung durch Wirkung des Eigengewichtes", Zeitschrift des Vereines Deutscher Ingenieure (Berlin), 1938, Vol. 82, No. 45, pp. 1301-1304.

This paper is a description of a method of prestressing developed by Finsterwalder and Dischinger. In this method the steel is usually placed outside of the main concrete member. The prestressing is achieved by stressing the cables which results in an upward deflection of the main concrete members. The same principle is applied to trusses.

1939

B13. Amos, H., "Stahlseitenbeton nach Hoyer", Zeitschrift des Vereines Deutscher Ingenieure (Berlin), 1939, Vol. 83, No. 11, pp. 337-338.

This short article describes the Hoyer system of prestressing. The manufacture of one I-beam is described and load-deflection curves are shown for beams with various amounts of prestress.

B14. Anderegg, F. O., "Progress in Prestressing Structural Clay Masonry", Bulletin of the American Ceramic Society, 1939, Vol. 18, No. 9, pp. 323-325.

A brief paper which describes prestressing of clay masonry units and their use as roof and deck flexural members. Tests of 6 slabs made from such units are described.

B15. Bornemann, E., "Neuere Verfahren im Eisenbeton", Zement (Berlin), 1939, Vol. 27, Nos. 46-48, pp. 727-730, 760-764, 744-747.

Various methods of prestressing are described and examples of structures given.

B16. Kleinlogel, A., "Stahlsaitenbeton", Stahl und Eisen (Düsseldorf), 1939, Vol. 59, No. 31, pp. 896-898.

This article deals mostly with the Hoyer system of prestressing although most of other works are briefly mentioned. The Hoyer method of prestressing is described in detail and the long line process of manufacture is mentioned.

B17. Meuller, P., "Brücken der Reichsautobahn aus Spannbeton", Die Bautechnik (Berlin), 1939, Vol 17, No. 10, pp. 128-135.

Description of two concrete bridges built in Germany. Test of prestressed concrete I-beam (for more detail description see Opperman 1940) described briefly. Of the two bridges one was pretensioned by Freyssinet's method and other post-tensioned by Dischinger-Finsterwalder method.

B18. Schoenberg, M.; Fichtner, F., "Die Adolf-Hitler-Brücke in Aue (Sa.)", Die Bautechnik (Berlin), 1939, Vol. 17, No. 8, pp. 97-104.

Description of a multispan bridge in Germany with three spans of prestressed concrete (Dischinger's method). Construction procedure described briefly.

B19. - - -, "Prestressed Reinforcement of Fine Wires Gives Spring to Precast Beams", Concrete, (Chicago), 1939, Vol. 47, No. 11, p. 8.

Brief description of Hoyer's method of prestressing with

2 mm. piano wire using bond to anchor wires. Beams, joists, and planks are precast and stock piled. Cast in molds 100 m. (328 ft.) long and cut to desired length.

1940.

B20. - - -, "New Type of Hut", Concrete and Construction Engineering, (London), 1940, Vol. 35, No. 6, p. 291.

War time huts built of precast slabs prestressed with piano wire. Very brief explanation.

B21. - - -, "Prestressed 108 ft. Girders in German Bridge", Engineering News Record, March 28, 1940, Vol. 124, No. 13, p. 452.

102 ft. clear span of prestressed concrete. Girders are of I-section and are about 5 ft. deep. Both longit. steel and stirrups are prestressed. High strength steel was used. Bridge spans express highways between Ruhr and Hanover.

1941

B22. Dill, H. E., "Some Experience with Prestressed Steel in Small Concrete Units", Proceedings, American Concrete Institute, 1941, Vol. 38, No. 2, pp. 165-168.

Description of the first fence posts of prestressed concrete (1928-29) and of small slabs used for roofs and for small house construction. Load deflections curves for two beams tested - one with and one without prestress.

B23. Mautner, K. W., "Saving Reinforcement by Prestressing", Concrete and Constructional Engineering (London), 1941, Vol. 36, No. 2, pp. 73-95.

This is a reply to Abeles paper of the same title. Mautner opposes partial prestressing.

1942

B24. Lossier, H., "Types de ponts en béton armé avec armatures précontraintes reglables", Genie Civil (Paris), 1942, Vol. 119, Nos. 21, 22, pp. 253-257, 269.

The author describes various large bridges of prestressed concrete. In conclusion he sums up the advantages of prestressed structures and discusses the possibility of using expanding cements.

1943

B25. Billner, K. P., "Electric Prestressing of Reinforcing Steel Used for Small House Construction", Engineering News Record, September 9, 1943, Vol. 131, No. 11, pp. 406-408.

2 1/2" thick walls prestressed with mild steel rods stretched by heating electrically; stretched rods fixed with nuts.

B26. Billner, K. P.; Carlson, R. W., "Electric Prestressing of Reinforcing Steel", Proceedings, American Concrete Institute, 1943, Vol. 39, No. 6, pp. 585-592.

Description of prestressing the steel by heating electrically and tightening the elongated rods by end nuts. Bars coated with sulphur and embedded in the concrete. Description of bond, fire and load tests with electrically prestressed structural members.

B27. Paul, A. A., "The Use of Precast Prestressed Concrete Beams in Bridge Deck Construction", Journal, Institute of Civil Engineers, (London), 1943, Vol. 21, No. 1, pp. 19-30.

Use of pretensioned beams, mostly of I-cross section, in Great Britian.

B28. Redonnet, "Une novelle application du beton precontraint, Les pontsdalles d'Elbeuf-sur-Andelle et de Longrov", Travaux (Paris), 1943, Vol. 27, No. 124, pp. 347-359.

A description of several prestressed slab bridges. Prestressing by Freyssinet method. A rather detailed description of construction procedures. Brief summary of the designs is presented. Some data on the test of one of the slabs are given.

1944

B29. Maney, G. A., "High Strength Reinforced Concrete Columns Developed", Civil Engineering, 1944, Vol. 14, No. 12, pp. 496-498.

A war-time development of spiral columns with prestressed spiral. High strength concrete obtained through use of low w/c ratio, vibrating and applying of pressure during hardening.

B30. Stucky, A.; Bolomey, J.; Panchaud, F., "Béton et béton précontraint", Bulletin Technique de la Suisse Romande (Lausanne), 1944, Vol. 70, No. 12, pp. 149-155.

Stucky's part is a description of the construction of a railroad bridge of prestressed concrete. Bolomey discusses the control of concrete and the third author compares the behavior of ordinary reinforced concrete with the behavior of prestressed concrete.

1945

B31. Benito, C., "Aportatión al estudio de estructuras pretensados", Laboratorio Central de Ensayo de Materiales de Construccion, Publicacion No. 10, Madrid 1945.

This paper gives a description of a method of determining the tension in a steel wire by measuring the frequency of vibrating wire. Tests conducted to check the accuracy of the formulas showed deviations of $\pm$ 4 percent.

B32. Benito, C., "Dispositivo de tensión en las armaduras del hormigón pretensado", Laboratorio Central de Ensayo de Materiales de Construccion, Publicaccion No. 3, Madrid, 1945.

Brief description of various methods of prestressing used in connection with existing structures.

B33. Marcus, H., "Prestressed Concrete Design Overseas", Engineering News Record, April 5, 1945, Vol. 134, No. 14, pp. 455-458.

Description of dams in which prestressing was used to make it possible to increase their height. Beams, bridges and caisons of prestressed concrete are also described.

1946

B34. Barber, R. S. V.; Lester, D. R., "The Development and Manufacture of Prestressed Concrete Units", Transactions, Society of Engineers (London), 1946, pp. 41-75.

Description of the manufacture of concrete sleepers at the Tallington Prestressed Concrete Factory.

B35. Billig, K., "Concrete Shell Roofs with Flexible Molds", Journal, Institute of Civil Engineers, (London), 1946, Vol. 25, No. 3, pp. 228-231.

Prestressing of shell roofs in the direction normal to the arch span. Description of this type of structure with a very brief description of the construction procedure.

B36. Lalande, M., "L'emploi du béton précontraint dans la fabrication des ouvrages d'art", Travaux (Paris), 1946, Vol. 30, No. 142, pp. 281-298.

Detailed description of the construction of the bridge Luzancy on the Marne. Bridge girders were precast in parts. Bridge was designed by Freyssinet.

B37. Mason, J., "A Report on Structural Engineering in Germany", Structural Engineer (London), 1946, Vol. 24, No. 6, pp. 310-314.

A very brief report of German activities in the field of prestressed concrete. Description of various methods of prestressing.

B38. Shama, R. E., "Garage in India is Built with Prestressed Concrete", Concrete (Chicago), 1946, Vol. 54, No. 7, pp. 22-24.

Description of an arch roof built of prestressed concrete. Freyssinet type of prestressing.

B39. Widman, M., "La passerelle publique pour pretons de Bully-Grenay en béton précontraint", Travaux (Paris), 1946, Vol. 30, No. 136, pp. 45-55.

A rather complete description of the construction of a pedestrian bridge prestressed by Freyssinet method. Summary of design given. Good description of prestressing operations.

B40. - - -, "A Prestressed Concrete Footbridge", Concrete and Constructional Engineering (London), 1946, Vol. 41, No. 5, pp. 139-140.

Very brief article giving dimensions and properties of the girders of the two span bridge built over tracks at the Bully-Grenay Station of the French National Railways. Comparison of quantities of material for prestressing and ordinary reinforced concrete is given.

B41. - - -, "Arch Roof in Prestressed Concrete," Concrete and Constructional Engineering (London), 1946, Vol. 41, No. 4, pp. 112-115.

This is taken from an article by R. E. Shama, "Garage in India is built with prestressed concrete", in Concrete 1946, Vol. 54, No. 7, pp. 22-24.

B42. - - -, "Development and Manufacture of Prestressed Concrete Sleepers", Railway Gazette, (London), May 17, 1946, Vol. 84, No. 20, p. 538.

This is an abstract from paper by Barber and Lester, "The Development and Manufacture of Prestressed Concrete Units". Transactions of the Society of Engineers, 1946, pp. 41-75.

B43. - - -, "Prestressed Concrete Sleepers", Concrete and Constructional Engineering, 1946, Vol. 41, No. 6, pp. 168-170.

The manufacturing of concrete sleepers at the Dow-Mac Products Ltd. in England is described step by step. Bonded prestress is used. For more complete information see Barber and Lester, "The Development and Manufacture of Prestressed Concrete Units", 1946, Transactions of the Society of Engineers, pp. 41-75.

B44. - - -, "Prestressed Reinforced Concrete Aeroplane Runways", Concrete and Constructional Engineering (London), 1946, Vol. 41, No. 11, p. 310.

Freyssinet is experimenting in this field. Builds runway in series of triangles. Stresses with unbonded wires (wires anchored in abutments) normal to direction of runway. Because of triangles a uniform compressive stress is induced in concrete in all directions. No results of these experiments are stated.

B45. - - -, "Reinforced Concrete Dams in France", Concrete and Constructional Engineering, (London), 1946, Vol. 41, No. 11, p. 324.

Prestressing is used in dams to conserve materials. By anchoring dam to the foundation with prestressing cables the line of pressure is altered to increase factor of safety. It is said that one ton of prestressed steel in these ties saves 450 cu. yd. of concrete.

1947

B46. Abeles, P. W., "Developments in Prestressing in Switzerland", Concrete and Constructional Engineering (London), 1947, Vol. 42, No. 12, pp. 377-378.

Short paper describing the uses of prestressed concrete in Switzerland. Both Hoyer's and Freyssinet's systems are used. Use of x indented wire and deformed strips of high strength steel.

B47. Booth, E. H., "Aerodrome Developments in India", Journal, Institute of Civil Engineers (London), 1947, Vol. 29, No. 2, pp. 154-160.

General description of a large aircraft hangar of prestressed concrete.

B48. Harris, A. J., "Prestressed Concrete Bridges", Concrete and Constructional Engineering (London), 1947. Vol 42, No. 11, p. 327.

Description of various European bridges: small bridges with precast prestressed beams, slab bridges, girder bridges, multiple span bridges and arches.

B49. Magnel, G., "Le béton-armé aux Etats-Unis", La Technique des Travaux (Paris), 1947, Vol. 23, Nos. 1-2, pp 17-24.

Short description of prestressed concrete tanks, of precasting techniques and other concrete construction

B50. Moyle, R. L., "Precast Prestressed Concrete Rail Bridge," Railway Age, (New York), 1947, Vol. 123, No. 12, pp 478-482.

Describes a railroad bridge (Adam Viaduct) in England The

girders of Approx. 30 ft. span are prestressed apparently by the Magnel system. Gives description of the manufacture of the beams and construction processes.

B51. Roessinger, F., "Le pont sur la Medjerdah à Djédeida", Bulletin Technique de la Suisse Romande (Lausanne), 1947, Vol. 73, No. 6, pp. 69-76.

Description of the construction of a three-span continuous bridge with hinges built in prestressed concrete in Tunis. Girders were precast, then prestressed by Freyssinet method. Performance tests of various kinds were conducted to determine: 1. resistance to shear of the joints between the individual precase elements; 2. resistance to bending of the beams; 3. resistance to shear; 4. losses of prestress; 5. resistance of the grout against injection into the cable sheaths.

B52. Sexton, C. G., "Prestressed Reinforced Concrete Hangar at the Civil Airport of Karachi," Journal, Institute of Civil Engineers (London), 1947, Vol. 29, No. 2, pp. 109-130.

Description of the method of construction of large prestressed concrete girders - Freyssinet method.

B53. - - -, "A Prestressed Concrete Bridge in Tunis", Civil Engineering and Public Works Review, (London), 1947, Vol. 42, No. 491, p. 203.

Describes very briefly a precast prestressed bridge of three spans, prestressed by the Freyssinet method. For more complete information see article by M. F. Roessinger in Bulletin Technique de la Suisse Romande, 1947, Vol. 73, No. 6, pp. 69-76.

B54. - - -, "A Prestressed Concrete Railway Bridge Near Wigan", Concrete and Constructional Engineering (London), 1947, Vol. 42, No. 10, p. 305.

Short description of a viaduct bridge. Saved 15 percent headroom over regular reinforced concrete. Girders had I-beam cross-section. Two I-beams were tested with 150 percent live load-no cracks occurred-immediately resumed its original elastic curve upon removal of load.

Adam viaduct between Wigan and Pemberton.

B55. - - -, "New Road Bridge at Luzancy, France", Concrete and Constructional Engineering, (London), 1947, Vol. 42, No. 1, pp. 17-20.

Description of single span bridge of 180 ft. span designed by Freyssinet. Hollow girder precast in blocks about 8 ft. long. Each girder was erected in 3 pieces. Between hinged end of beam and abutment a form of jack is provided to regulate at any time the thrust on the abutment.

B56. - - -, "Precast Prestressed Concrete Rail Bridge", Engineering, (London), 1947, Vol. 164, No. 4259, p. 252-263.

Describes a railroad bridge (Adam Viaduct) in England. The girders of approximately 30 ft. span are prestressed apparently by the Magnel system.

B57. - - -, "Precast Prestressed Concrete Rail Bridge", The Engineer, (London), 1947, Vol. 184, No. 4771, pp. 10-11.

Describes a railroad bridge (Adam Viaduct) in England. The girders of approximately 30 ft. span are prestressed apparently by the Magnel system.

B58. - - -, "Reconstruction of Bridges in France", Concrete and Constructional Engineering (London), 1947, Vol. 42, No. 3, pp. 94-97.

Among other bridges two of prestressed concrete (the bridge of Lajout, Marseilles and Canal Bridge at Montcresson) are very briefly described. The prestressed features of the bridges are told giving quantities of wire used and savings over reinforced concrete.

B59. - - -, "The Use of Expanding Cement Concrete", Concrete and Constructional Engineering (London), 1947, Vol. 42, No. 1, p. 16.

An expanding cement (of untold content) is introduced into form and its expansion exerts compression on rest of structure. Sites 3 or 4 examples of this material used for patching and repairing war damaged structures.

1948

B60. Courty, L.; Kaleski, R., "La nouvelle cuverie a vin de Cinzano en béton précontraint", Travaux (Paris), 1948, Vol. 32, No. 165, pp. 421-429.

Description of the construction of a winery. The vats are of prestressed concrete.

B61. Freyssinet, E., "Ponts en béton précontraint", Int. Assoc. Bridge and Struct. Eng., Third Congress, Final Report, Liége 1948, pp. 405-420.

Description of various types of prestressed concrete bridges with examples of actually built structures.

B62. Haggbom, I., "The Bridge at Sandö", Int. Assoc. Bridge and Struct. Eng., Preliminary Publication, Liége 1948, pp 381-392.

Only the last part of this paper - pp. 391-392 - deals

with prestressed concrete. A girder is described which was prestressed with tie rods of tensile strength 52 kg/mm^2.

B63. Magnel, G., "Les application du béton précontraint en Belgique", Int. Assoc. Bridge and Struct. Eng., Third Congress, Preliminary Publication, Liege, 1948, pp. 333-342.

Magnel describes his method of anchoring the prestressed wires with sandwich plates and then gives examples of several structures giving the details of the prestressed members. Some comparison of the costs of reinforced and prestressed concrete structures.

B64. Schofield, E. R., "First Prestressed Bridge in U.S.A.", Engineering News Record, December 30, 1948, Vol. 141, No. 27, pp. 16-18.

Report of the design of first prestressed concrete bridge in USA made for the City of Philadelphia (Walnut Lane Bridge). Few technical data included.

B65. Williams, W. H., "B.O.A.C. Office Extension", The Builder (London), 1948, Vol. 175, No. 5518, pp. 595.

Precast, prestressed concrete columns were used in a one story building. Freyssinet system of prestressing was used.

B66. - - -, "Concrete Sleepers in Belgium", Concrete and Constructional Engineering (London), 1948, Vol. 43, No. 6, pp. 279-281.

Describes two types of concrete sleepers used in Belgium--the Blaton sleeper designed by Magnel and the Franki--Bagon sleeper. Both have been proven in actual service. The manufacturing and prestressing operations are described.

B67. - - -, "Inducing Initial Stresses in Waterloo Bridge", Concrete and Constructional Engineering (London), 1948, Vol. 43, No. 1, p. 25.

7/8", 1", and 1 1/8" bars were used for prestressing-bars had upset ends and were tightened with nuts or turn-buckles--medium high steel was used and only stressed to 45,000 psi.--bars were elongated with steam heat, the amount of elongation being measured by number of turns of nut or turnbuckle.

B68. - - -, "Prestressed Bridge at l'Hermillon, France", Concrete and Constructional Engineering (London), 1948, Vol. 43, No. 1, p. 21.

Brief description of this bridge--single span of 163 ft.--precast beams--prestressed a la Freyssinet--beams were of solid I-section. Some difficulty was experienced in stretching the cables where these were bent up towards the ends of the beams as the wires were old and slightly rusty. The required elongation of each cable was obtained by repeating the jacking operation.

B69. - - -, "Prestressed Cast In-situ Concrete Bridge," Engineering (London), 1948, Vol. 165, No. 4300, pp. 608-609.

A description of Nunn's Brudge over Hob Hole drain at Fishtoft, near Boston, Lincolnshire. 72 ft. clear span bridge of prestressed girders cast in place. Prestressing was carried out in accordance with Freyssinet process and is explained here.

B70. - - -, "Prestressing Applied to Stregthening a Church Tower in Staffordshire," Concrete and Constructional Engineering, (London), 1948, Vol. 43, No. 9, pp. 280-283.

Describes how a tower which was settling and tilting and cracking due to a mining subsidence, was straightened up and strengthened by inserting in the walls prestressed beams of Magnel design. Other descriptions appear elsewhere in these references e.g. in Magnel's book.

B71. - - -, "Reconstruction of Nunn's Bridge, Lincolnshire", Concrete and Constructional Engineering (London), 1948, Vol. 43, No. 8, pp. 239-244.

Cast in place bridge--five girders of 74 ft. span--prestressed by Freyssinet process. Dimensions of girders, wires, etc. are given--also description of construction processes.

B72. - - -, "Reconstruction of Quay Walls, Le Harvre, Composite In-situ and Precast Prestressed Beams", Concrete and Constructional Engineering, (London), 1948, Vol. 43, No. 2, pp. 55-57.

Description of the structure which includes prestressed beams and slabs. Prestressing by Freyssinet process is explained.

B73. - - -, "Some Prestressed Concrete Buildings in Belgium", Concrete and Constructional Engineering, 1948, Vol. 43, No. 7, pp. 193-199.

A brief description of some of the buildings of Magnel's design. Hangar at Brussells Airport; textile factory at Ghent; underpinning of tower at Tournai Better descriptions appear in Magnel's book and elsewhere in these references.

B74. - - -, "Supporting a Structure During Reconstruction". Concrete and Constructional Engineering (London), 1948, Vol. 43, No. 3, pp. 93-95.

Explains how 4th and 5th floors of a maltery were supported while 4th floor columns were removed for reconstruction. Nother here about prestressed concrete. The maltery is in Mistleu, Essex.

1949

B75. Brewster, F. R., "Concrete Building Columns Prestressed", Engineering News Record, November 10, 1949, Vol. 143, No. 19, pp. 34-36.

Precast prestressed columns for a factory hall used in order to save steel. Columns designed to take tension due to eccentric loading. Columns carried the roof and crane.

B76. Chalos, M., "Armatures souples pretendues", Travaux (Paris), 1949, Vol. 33, No. 178, pp. 330-331.

Description of flexible prestressing cable, the method of its placing and prestressing.

B77. Coff, L., "Prestressed Concrete - A New Frontier", Engineering News Record, September 1, 1949, Vol. 143, No. 9, p. 183-187.

The author describes some of the more important techniques of prestressing and gives a brief history of prestressed concrete.

B78. Coff, L., "Prestressing Increases the Uses of Precast Structural Concrete", Rock Products (Chicago), 1949, Vol. 52, No. 11, pp. 110-112, 117.

Cites examples of precast prestressed units in Europe. Explains the use of prestressing and points out that prestressing should make precast elements more economical.

B79. Dobell, C., "Design Progress in Prestressed Concrete," Progressive Architecture, 1949, Vol. 30, No. 10, pp. 84-87.

Description of construction of some recent buildings with long spans built in Europe under Magnel's direction. Short description of Preload method of prestressing tanks.

B80. Duyster, H. C., "Vliegtuigloodsen in spannbeton", (Prestressed Concrete hangars), De Ingenieur ('s-Gravenhage), 1949, Vol. 61, No. 18, pp. 37-48. Also in Cement (Amsterdam), 1949, Vol. 1, No. 7-8, pp. 117-124.

Very comprehensive description of large prestressed concrete girders, as well as their construction and erection. Some design theory added.

This paper has been translated in English and published under the title "The Construction of Aircraft Hangars in Prestressed Concrete at the Melsbroek Airfield near Brussels", Bulletin No. 12, Cement and Concrete Association, London, 1950.

B81. Lämmlein, A.; Wichert, U., "Spannbetonbrücke Bleibach", Die Bautechnik (Berlin), 1949, Vol. 26, No. 10, pp. 300-306.

Description of prestressed concrete skew slab bridge in Germany. Prestressed by post-tensioned cables. Detail description of the structure and prestressing procedure as well as of anchoring the cables given. Strain measurements made during prestressing operations are also given.

B82. Lossier, H., "Pont sur la Seine, à Villeneuve-Saint-Georges," Travaux (Paris), 1949, Vol. 33, No. 178, pp. 327-329.

Description of the bridge with four simple spans. Each span consists of three hollow prestressed girders.

B83. Magnel, G., "Prestressed Concrete Beams Carry Record Loads in Belgium Hangar," Engineering News Record, February 10, 1949, Vol. 142, No. 6, pp. 18-19.

Framing plan for an airplane hangar is given and the heaviest girder is described. It has a span of 42 ft. and is of hollow rectangular cross section. The prestressing wires are grouted in.

B84. Ouziel, R., "Le pont a 3 travees de 35 metres sur l'oued Melah", Travaux (Paris), Vol. 33, No. 178, pp. 337-342, 1949

Description of a bridge in Tunisia made up of prestressed concrete I-beams. The manufacture of beams and construction of the bridge are well described.

B85. Riessauw, F.; Vandepitte, D.; Dooms, J.; Van Cauwenberge, M., "Le nouveau pont en béton précontraint de la rue De Smet sur la Canal de Raccordement, a Gand", Annales de Travaux Publics de Belgique (Bruxelles), 1949, Vol. 102, No. 6, pp. 687-720.

Description of a bridge built in Belgium. Bridge consists of simple span beams prestressed by Magnel system. Detailed description of construction procedures is given and the design of the bridge is also mentioned.

B86. Schofield, E. R., "Construction Starts on Prestressed Concrete Bridge in Philadelphia", Civil Engineering, 1949, Vol. 19 No. 7, pp. 32-34.

Description of the structure, the preliminary planning The relative costs of other types of structures discussed. Essentially the same material as Schofield's article "First Prestressed Bridge in USA" (ENR December, 1948).

B87. Schofield, E. R., "Prestressed Concrete Used for Boldly Designed Structures in Europe", Civil Engineering, 1949, Vol 19, No. 9, pp. 22-27.

A report of the present state of prestressed concrete construction with description of sample structures in France, Belgium, Sweden and England.

B88. Streblow, "Prestressed Slabs and Prestressed Walls," Concrete (Chicago), 1949, Vol. 57, No. 4, pp. 314.

Description of the fabrication of prestressed slabs and walls manufactured by the Basalt Rock Company, Mapa, California.

B89. - - -, "Bridges in Prestressed Concrete", Civil Engineering and Public Works Review (London), 1949, Vol. 44, No. 520, pp. 586-588.

Description of one overpass over railroad in England constructed with precast prestressed concrete beams. One of the precast beams was tested to failure; it failed by crushing of concrete. Description of test very incomplete.

B90. - - -, "Gauging Wire in Prestressed Tanks", Engineering News Record, October 6, 1949, Vol. 143, No. 14, pp. 33-34.

The stress in the prestressing wires of a large water tank is determined by the vibration frequency measured with a magnetic pick-up and an oscillograph.

B91. - - -, "Hormigon precomprimido. Ensayo de un tipo de entrepiso en neustro Campo Experimental," Cemento Portland (Buenos Aires), 1949, Vol. 4, No. 21, pp. 3-8.

Description of slabs prefabricated of small precast prestressed elements combined with hollow tile fillers and monolithic concrete wearing surface. Test of one of such slabs is described.

B92. - - -, "Jointless Prestressed Warehouse Floor", Engineering News Record, January 6, 1949, Vol. 142, No. 1, pp. 68-69.

The jointless prestressed concrete slab 96' by 144' is described. Anchorage of the cables, and prestressing operation is explained.

This is the slab in the Roebling Warehouse at Cicero, Illinois.

B93. - - -, "Prestressed Cast-in-Place Concrete Bridge", Concrete, (Chicago), 1949, Vol. 57, No. 3, pp. 3-5.

A description of Nunn's Bridge over Hob Hole drain at Fishtoft, near Boston, Lincolnshire. The girders are built in the conventional manner, except they are cast in place. Freyssinet's system of prestressing was used.

B94. - - -, "Prestressed Concrete Beams in a Building at Edinburgh", Concrete and Constructional Engineering, (London), 1949, Vol. 44, No. 11, pp. 353-356.

Three story building has prestressed floor members. Main girders are of 20 ft. span are precast prestressed by Magnel system. Secondary girders are 30 ft. span are produced in factory and are bonded prestress.

B95. - - -, "Prestressed Concrete Bridges Over the River Marne, Spans of 242 ft. 9 ins," Concrete and Constructional Engineering, (London), 1949, Vol. 44, No. 12, pp. 378-385.

These bridges designed by Freyssinet process are 2-hinged arches and the arches are precast in blocks and assembled into 3 or 4 parts before placing on piers. Final assembly is completed when the arches are in place. The hinges embody a device for regulating the thrust and the span by means of a jack. The dimensions and the prestressing operations as well as the construction processes are explained.

B96. - - -, "Prestressed Concrete Sleepers," Concrete and Constructional Engineering (London), 1949, Vol. 44, No. 9, pp. 294-296.

Wires in form of links are bonded in concrete and positively anchored in molds. Ends of each pair of links pass around cast-iron anchor blocks. Block at one end of link is secured by anchor bolt to end plate of mold and at other end by bolt which passes through mold.

B97. - - -, "Two Notable New Prestressed Concrete Buildings", Civil Engineering and Public Works Review (London), 1949, Vol. 44, No. 521, pp. 660-664.

Description of the structure of an extension of a factory and of a 3 story office building in England, both in prestressed concrete. Construction procedures are also given. In the first the Freyssinet, in the second the Magnel system of prestressing were used.

1950

B98. Benijaminavicius, Ph., "Les hangars en béton précontraint de l'aéport de Melsbroek", Annales des Travaux Publics de Belgique, (Bruxelles), 1950, Vol. 103, No. 6, pp. 841-890

Description of hangars at Melsbroek and of their construction with particular attention to the prestressed elements: beams and columns of various sizes and shapes.

B99. Billner, K. P., "New Prestressing Method Utilizes Vacuum Process", Proceedings, American Concrete Institute, 1950, Vol. 47, No. 2, pp. 161-176.

A prestressing method is described in which steel rods are embedded in the concrete consisting of two separate halves. The bars are bonded at both ends with hooks, the remaining portions are coated with asphalt and thus remain unbonded. After the concrete hardens the two parts of the beams are pushed apart and fixed in position with concrete. The paper is supplemented by the results of a test of one beam - tested to destruction and with a design procedure.

B100. Birguer, A., "Reconstruction du pont de Sclayn sur la Meuse", Travaux (Paris), 1950, Vol. 34, No. 187, pp. 315-324.

Description of the reconstruction of the Sclayn Bridge in Belgium. Some design calculations are also included.

B101. Cousins, H. G., "The Application of Prestressing to Shell Roof Structures", The Reinforced Concrete Review (London), 1950, Vol. 2, No. 3, pp. 189-199.

The method of prestressing the shells is described and the construction procedure discussed.

B102. "Weitgespannte Stahlbetonbalkenbrücken mit Vorspannung durch Seile und nachtraglichem Verbund", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 5, pp. 97-99.

Description of a new method of prestressing the continuous beams over the supports. The bridge discussed consists of one large hollow girder.

B103. Feld, J., "Prestressing Cuts Homebuilding Costs", Engineering News Record, September 14, 1950, Vol. 145, No. 6, pp. 48-50.

Prestressing of precast wall, floor and roof slabs. Emphasis placed on simplicity of the prestressing method. Slabs prestressed with 1/4 in. wire with a button head on one end and a thread on the other end. Stress in wire determined by elongation and with the aid of a tuning fork.

B104. Franz, "Westeuropäische Bauten aus vorgespannten Beton", Der Bauingenieur (Berlin), 1950, Vol. 25, No. 1, pp. 27-31.

Buildings and Bridges built of prestressed concrete in Western Europe (especially Belgium) are described with respect to method of prestressing and erection.

B105. Giraud, R., "Le Pont d'Essey", Travaux (Paris), 1950, Vol. 34, No. 186, pp. 261-267.

Description of prestressed concrete arch bridge. Construction details and design features and formulas are given.

B106. Goldstein, A., "Design and Construction of Prestressed Concrete Arch Footbridge at Oxford", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 10, pp. 347-356.

A small fixed arch foot bridge prestressed with vertical, diagonal, and horizontal cables. Main arches cast in place, slab precast. Construction procedure described and illustrated. Design procedure and formulas given.

B107. Kaiser, A.; König, H., "Die Herdbrücke in Ulm und die Inselbrücke in Neu-Ulm", Der Bauingenieur (Berlin), 1950, Vol. 25, No. 5, pp. 153-159; No. 10, pp. 379-384.

Description of two prestressed concrete arch bridges during construction.

B108. Komendant, A. E., "Prestressed Concrete Arch Spans 353 ft.", Engineering News Record, December 7, 1950, Vol. 145, No. 23, p. 48.

Description of World's largest prestressed concrete span which consists of two three-hinged arches. Each arch is of the hollow box type and is prestressed with wire ropes 1 1/2" in diameter anchored in abutments. This bridge was built in Germany as replacement of a destroyed reinforced concrete bridge. It has 40 percent less steel, 16 percent less concrete and it took 15 percent less manhours to build it than for the original bridge. (Over Neckar Canal in Harbor of Heilbronn, Germany).

B109. Lämmlein, A., "Über die Wirtschaftlichkeit von Spannbeton-Strassenbrücken", Beton-und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 3, pp. 66-68.

This article discusses the economy of prestressed concrete bridges with respect to reinforced concrete bridges and steel bridges.

B110. Lämmlein, A.; Bauer, A., "Spannbetonbrücken Emmendingen", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 9, pp. 197-203.

Description of a three-span continuous skewed highway bridge of prestressed concrete. Prestressed according to Leonhardt-Baur system in which the wire is wrapped continuously around concrete semi-circular anchorages which are jacked appart to stretch the wire.

B111. Lee, D., "A New System of Prestressed Concrete", Civil Engineering and Public Works Review (London), 1950, Vol. 45, No. 527, p. 299.

Description of newly developed high tensile steel bars of diameters up to one inch. The bars are pretensioned with the aid of threaded ends. Bars may be coupled together. This steel is free of creep and fairly resistant to heat treatment. Also jack for prestressing these bars is described.

B112. Leonhardt, F.; Baur, W., "Brücken aus Spannbeton. wirtschaftlich und einfach. Das Verfahren Baur-Leonhardt," Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, Nos. 8-9, pp. 182-188, 207-215.

Discussion of Magnel's and Freyssinet's methods of prestressing. Description of authors' method in which the prestressing wire is wrapped around half-cylindrical anchorages at the ends of the beam and prestressed by jacking the anchorages apart. Various bridges are

discussed in the second part primarily with respect to the method of prestressing.

Discussions:

Finsterwalder, U, Franz, G: dtto, 1951, Vol. 46, No. 4, pp. 90-91.
Leonhardt, F.; Baur, W.: dtto, 1951, Vol. 46, Nos. 5-6, pp. 114-116, 133-135.
Dischinger, F.: dtto, 1951, Vol. 46, No. 6, pp. 131-133.

B113. Lossier, H., "La précontraint intégral mixte", Le Génie Civil (Paris), 1950, Vol. 127, No. 21, pp. 412-413.

Author discusses briefly the use of expanding cements as the prestressing agent for prestressed concrete.

B114. Macerata, S., "Prestressed Concrete Conductor Masts in South Africa", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 1, pp. 13-19.

U-shaped tapered masts used as utility posts are described. Manufacture of these posts and tests are also described. The tests were carried to failure and the results are plotted as load-deflection curves.

B115. Magnel, G., "Longest Continuous Prestressed Girders Carry Scalyn Bridge Traffic Over Meuse River", Civil Engineering, 1950, Vol. 20, No. 7, pp. 450-451.

Description of two span continuous girder bridge in Belgium. Arrangements were made on this bridge which enable one to take measurements on two prestressing wires at any time. This was done in order to secure information on the effects of creep, shrinkage, relaxation and temperature.

B116. Masterman, O. J., "Process for the Manufacture of Prestressed Concrete Floor Joists", Civil Engineering and Public Works Review, 1950, (London), Vol, 45, No. 532, pp. 641-643.

Summary of the work aiming at the design of an inexpensive mold and at devising a commercial method of obtaining nearly high strength in the concrete of prestressed floor joists. Description of anchoring and tensioning devices for single wires.

B117. May, D. H., "The Magnel-Blaton System of Prestressing", Reinforced Concrete Review (London), 1950, Vol. 2, No. 2, pp. 135-139.

Description of the mechanics and operation of the Magnel prestressing jacks. Discussion of possible corrosion. Most of this material is in Magnel's book "Béton Précontraint".

B118. Nordberg, B., "Prestressed Floor and Roof Slabs of Concrete Masonry Units", Rock Products (Chicago), 1950, Vol. 53, No. 1, pp. 197-201.

Description of walls and slabs composed of masonry units connected by prestressing - work of Basalt Rock Company, of Napa, California.

B119. Panchaud, F., "Quelques ouvrages én béton précontraint construits récemment en Suisse", (Various structures of prestressed concrete recently constructed in Switzerland), Bulletin Technique de la Suisse Romande (Lausanne), September 23, 1950, Vol. 76, No. 19, pp. 257-266.

The construction of a wharf (débarcadère de Nym), a railway bridge and highway bridge (le pont-rail et la pont-route de Zwingen) is described. Each of these structures utilized precast, post-tensioned girders. Freyssinet cables were used.

B120. Seegers, K. H., "Vorgespannte Betonfertigteile bei den englischen Eisenbahnen", Der Bauingenieur (Berlin), 1950, Vol. 25, No. 12, p. 457.

A short article discussing precast, prestressed beams built in England with respect to the method of manufacture and the type of beam.

B121. Storrer, E., "Le pont de Scalyn sur la Meuse", Annales Travux Publics de Belgique (Bruxelles), 1950, Vol. 103, Nos. 2, 4, pp. 179-199, 603-622.

A description of the two-span continuous bridge of prestressed concrete designed by Magnel. The prestressed design is compared with designs in reinforced concrete. Prestressing and construction are also described briefly and reference is made to the design procedure.

B122. Sunderland, C. C.; Preston, H. K., "Americanized Prestressed Concrete Emerges From the Laboratory", Engineering News Record, March 2, 1950, Vol. 144, No. 9, pp. 34-37.

Description of the construction of prestressed concrete slabs from separate units. Prestressed in both directions with galvanized bridge cables.

B123. Tourry, G., "Reconstruction de la tour du phare de Berck en béton précontraint", Travaux (Paris), 1950, Vol. 34, No. 194 pp. 781-786.

Description of the construction of a lighthouse built of precast elements tied together by prestressing. Prestressing was done by the Freyssinet method.

B124. Wolf, W., "Das Kreuzungsbauwerk Kirchheim als Beispiel einer Spannbetonbrücke", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 6, pp. 145-146.

Description of the construction of a two-span highway crossing built of precast prestressed concrete beams in Germany near Kirchheim, Kreis Hersfeld.

B125. Wolf. W., "Verfahren und Ergebnisse der Ausschreibung 'Wilhelmsbrucke' Frankfurt-Main", Die Bautechnik (Berlin), 1950, Vol. 27, No. 9, pp. 281-288.

Various bridges along this highway from Frankfurt to Main are described--some of which are of prestressed concrete.

B126. - - -, "A Continuous Bridge in Prestressed Concrete", The Reinforced Concrete Review (London), 1950, Vol. 2, No. 2, pp. 139-144.

Description of the design and construction features of a two-span continuous prestressed concrete bridge at Sclayn, Belgium. The Magnel-Blaton system was used. Includes three photographs of the bridge under construction and two plates of design details.

B127. - - -, "A New Prestressed Concrete Sleeper", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 2, pp. 68-69.

Freyssinet designed a lighter weight sleeper for use on main lines by using higher strength concrete and reducing the cross section in the middle portion. Crimped wires are used to increase bond. Manufactured in long line to cut down prestress operation. Details for attaching rails are given.

B128. - - -, "A Prestressed Concrete Continuous-girder Bridge in Belgium", Concrete and Constructional Engineering (London) 1950, Vol. 45, No. 6, pp. 189-200.

Author describes the two span continuous Sclayn Bridge. Prestressing operations are discussed and design calculations shown.

B129. - - -, "A Prestressed Concrete Road Bridge in Lancashire", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 7, pp. 255-256.

Description of a prestressed concrete road bridge over river Tame in England.

B130. - - -, "Britian's First Prestressed Factories", Concrete Quarterly (Cement and Concrete Association, London), April, 1950, No. 8, pp. 28-32.

Description of three factories built of prestressed concrete, one by Freyssinet's, one by Magnel's and one by Strescon's system.

B131. - - -, "Cables Join Precast Beams to Form First Continuous Prestressed Bridge", Engineering News Record, August 31, 1950, Vol. 145, No. 9, pp. 30-31.

Description of the errection and prestressing processes on the 3 span continuous bridge at Neufchatel-en-Bray. Freysinnet system.

B132. "California Builds its First Prestressed Concrete Bridge", Engineering News Record, November 23, 1950, Vol. 145, No. 21, p. 42.

Description of the pedestrian bridge over Arroyo Seco Highway in Los Angeles.

B133. - - -, "Dauerbehelfsbrücken mit Spannbetonfertigträgern", Betnn-und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 6, pp. 128-129.

Short article describing precast, prestressed beam bridges and their advantages.

B134. - - -, "Der Bau Von zwei Spannbetonbrücken", Beton und Stahbetonbau (Berlin), 1950, Vol. 45, No. 6, pp. 137-139.

Description of two prestressed concrete bridges built by Freyssinet's method in Germany; a two span continuous structure near Ulm-Dornstad and a simple span structure near Nürenberg-Fürth.

B135. - - -, "Development Work at the Field Test Unit", Magazine of Concrete Research (London), 1950, Vol. 2, No. 4, pp. 35-37.

Very brief description of sustained load tests of floor joists made by the Field Test Unit in Great Britian. Description of development work on long line and individual unit processes of manufacture of prestressed concrete joists.

B136. - - -, "European Concrete", The Reinforced Concrete Review, (London), 1950, Vol. 2, No. 1, pp. 12-28.

This issue contains several brief illustrated articles describing: (1) The construction of a deep water quay using reinforced concrete caissons cast on shipways and floated into position and sunk. (2) The use of prestressed and precast members in the beam and girder floor of a warehouse. Abstracts of two lectures on prestressed concrete by Magnel and Freyssinet are presented at length, several pages being devoted to each.

B137. - - -, "Forspent betong i brobyggingen", (Bridge building in prestressed concrete), Betongen Idag (Oslo), 1950, Vol. 15, No. 4, pp. 79-87.

Description of bridges in Tunisia (Wadi Melah), Belgium (Sclayn), USA (Walnut Lane), France (Neufchatel) and Brazil (Galea) Same material as in the article "Multispan Prestressed Concrete Bridges", Concrete Quarterly, April 1950.

B138. - - -, "How They're Building Philadelphia's Famed Prestressed Bridge", Engineering News Record, September 21, 1950, Vol. 145, No. 12, pp. 32-34.

Brief description of the construction procedures employed at the Walnut Lane Bridge.

B139. - - -, "Multispan Prestressed Concrete Bridges", Concrete Quarterly (Cement and Concrete Association, London), April, 1950, No. 8, pp. 2-13.

Description of bridges in Tunisia (Wadi Melah), Belgium (Sclayn), USA (Walnut Lane), France (Mont de Terre and Neufchatel-en-Bray) and Brazil (Galeao).

B140. - - -, "Plant for Prestressed Concrete," Reinforced Concrete Review, (London), 1950, Vol. 2, No. 4, pp. 260-264.

Short report of the progress of the development work made by the Field Test Unit of the Ministry of Works. Anchoring devices described. Device for equalizing load on four wires stressed simultaneously. Jacks. Stress determination.

B141. - - -, "Precast Concrete in Government Buildings", Concrete and Constructional Engineering, (London), 1950, Vol. 45, No. 11, pp. 399-403.

Discussion of the use of prestressed concrete beams in buildings built for the government in England. Specific examples are discussed.

B142. - - -, "Prestressed Concrete Bridges in Yorkshire", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 3, pp. 99-100.

Description of two road bridges made up of unsymetrical prestressed I-beams placed side by side and filled in with concrete placed in situ.

B143. - - -, "Prestressed Concrete Footbridge", Reinforced Concrete Review (London), 1950, Vol. 2, No. 4, pp. 210-211.

Description of the pedestrian bridge over the Cherwell in Oxford University parks. It is an arch bridge prestressed by Freyssinet method.

B144. - - -, "Prestressed Cradles Pick up Bridge Piers," Construction Methods, 1950, Vol. 32, No. 1, pp. 46-48.

Description of prestressed beams which support bridge piers during a construction process. Method of tensioning the 3" square rods is explained. Not very complete.

1951

B145. Abeles, P. W., "Bonded Wire vs. Unbonded", Engineering News Record, July 26, 1951, Vol. 147, No. 4, p. 47. Reader Comment Section.

Bonded wires preferable. Combination of prestressed and unstressed wires mentioned. Economic advantages of prestressed concrete discussed.

B146. Astapkevic, P., "Montáž prumyslových staveb z předpjatého betonu", (Erection of industrial buildings of prestressed concrete), Stavební prumysl (Prague), 1951, Vol. 1, No. 15, pp. 357-358.

Discussion of problems of erection of prestressed concrete structures.

B147. Arribahaute, Beteille, "Pont de la Genevraye", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 230-232.

Description of the construction of a prestressed concrete bridge at Genevraye. Girders precast and prestressed with large cables. The fabrication of the girders is explained step by step.

B148. Barets, J.; Hervet, J.; Averseng, E.; "L'Evolution de la Précontrainte Enseignements déduits de la construction de divers ouvrages Pont d'Arles-sur-Tech," Travaux (Paris), 1951, Vol. 35, No. 200, pp. 408-412; No. 202, pp 491-496.

Pictures of several bridges of prestressed concrete built after the war are included in this article. However, the bridge (Pont d'Areles-sur-Tech) is described more completely than the others The construction of this bridge is also described.

B149. Barton, R. A., "Prestressed Bridge", California Highway and Public Works, 1951, Vol. 30, Nos. 3-4, pp 1-5, 28.

A description of the pedestrian bridge over Arroyo Seco flood channel in Los Angeles. Simple-span girders of 110-ft span. Detailed explanation of precasting and prestressing operations, prestressing with the help of button-type anchorages. Strain-measuring devices left in the structure for measurements under live load.

B150. Baskin, B. J., "Prestressing Applied to Manufacture of Precast Bridge Beams", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 221-223

This paper explains the manufacturing procedure of precast, prestressed, pretensioned beams for bridges. Tests were made to determine bond characteristics in the beam under loaded conditions for single notched wires and for 7-wire cables. It was concluded that a 1/4 in. diameter cable consisting of 7 strands was satisfactory for developing the bonds.

B151. Baxter, S. S.; Barofsky, M., "Construction of the Walnut Lane Bridge", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 47-56.

Description of the Walnut Lane Bridge. The reasons for choosing a prestressed concrete girder bridge is discussed. Cost data is given. Construction is described.

B152. Billner, K. P., "Mass-Produced Prestressed Concrete Units", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 112-125.

This paper describes the different methods of precasting and prestressing concrete members in factories in France, England, Italy, Sweden, and the United States. A discussion by D. O. McCall, of the Basalt Rock Company manufacturer of prestressed concrete beams, slabs, and other units, describes in more detail the methods employed in prestressing and uses made of prestressed concrete units in the United States.

B153. Birdsall, B., "Development of End Terminals", Proceedings of the First United States Conference on Prestressed Concrete Massachusetts Institute of Technology, August, 1951, pp. 224-227.

The end connections for prestressing cables as manufactured by John A. Roebling's Sons Inc., are briefly described.

B154. Bitzan, A., "Výroba a zkušenosti s dodatečně napínaným betonem", (Manufacture and experiences with pretensioned, prestressed concrete), Stavebni prumysl (Prague), 1951, Vol. 1, No. 15, pp. 350-353.

Outline of the principles which should be followed for obtaining good prestressed concrete products.

B155. Brodsky, A., "Mechanical Prestressing", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 7, p. 570. Letters from Readers Section.

Very brief description of Lossier's method precasting girders in two parts, with reinforcement embedded. Prestressing achieved by jacking the two parts of the beam apart after hardening of the concrete.

B156. Bryan, R. H.; and Dozier, C. B., "Prestressed Concrete Block Bridges", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 57-60.

A short paper outlining the use of blocks used as units in prestressed concrete beams. A series of pictures shows the manufacture of beams and their construction into a bridge in Madison County, Tennessee.

B157. de Buffevent, L., Lossier, "Villeneuve-Saint-Georges", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 210-212.

Description of cantilever prestressed concrete bridge at Villeneuve-St. George.

B158. Clarke, N. W. B., "A Flexible Mould Stop for Long Line Prestressed Concrete", Civil Engineering and Public Works Review (London), 1951, Vol. 46, No. 539, pp. 351-352.

A rubber spacer to be used between the units poured in a single mould in the long-time process of prestressing concrete has been developed. It is easy to place, does not move from its position during vibration of concrete, can be used over and over, and is economical to use. They can easily be made to any desired shape by the contractor.

B159. Coff, L., "Prestressed Concrete for Pavements", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 87-90.

This paper advocates the use of prestressed concrete for use in highway slabs; advantages are elasticity of prestressed concrete slabs, fewer expansion joints, minimum cracking, and less maintainance.

B160. Cummings, A. E., "Prestressed Concrete Piles", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 105-111.

This paper deals with the manufacture and use of prestressed concrete piles.

B161. Dumas, F., "L'evolution de la précontrainte du béton armé au cours de la reconstruction des ouvrages d'art du Nord et du Pas-de-Calais", Travaux (Paris), 1951, Vol. 35, No. 200, pp. 375-382; No. 201, pp. 419-435; No. 202, pp. 462-479; No. 203, pp. 506-514; No. 204, pp. 568-577.

This series of articles presents pictures and descriptions of various degrees of completeness of many prestressed concrete bridges built in the last few years in France. In addition various tests conducted are reported, such as: loss of prestress under load, tensile tests of wire, compressive tests of concrete.

B162. Duminy; Lebelle; Beaufil, "Tranchee couverte de Rouen," Travaux (Paris), 1951, Vol. 35, No. 196, pp. 215-218.

Description of the structure and construction of a shed in Rouen. Beams of prestressed concrete.

B163. Fougea, E ; Cayla, M., "Nouveau mode de mise en précontrainte". Travaux (Paris), 1951. Vol. 35, No. 198, pp. 323-330.

The authors describe the method of prestressing used by "Constructions Edmond Coignet" in box girders. It consists of anchoring

the ends of the cables at the ends of beams and then deforming the cables laterally at several points along their length; this lateral deformation of the cables stretches them thus tensioning them. It is claimed that this method gives a better distribution of tension in the cable than in a curved cable which is post-tentioned. A three span bridge (Pont de Vaux-sur-Seine) was prestressed in this manner and is discussed.

B164. Franz, "Le béton précontraint en Allemagne", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 246-247.

A brief paper which enumerates some of the structures built of prestressed concrete in Germany.

B165. Friberg, B. F., "The Challenge of Prestressing for Concrete Pavements", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 91-104.

This paper treats rather thoroughly the use of prestressed concrete for highway construction. Specifically the following topics are discussed: I. Existing State of Concrete Pavement; II. Scope of Prestressing in Concrete Pavements; III. Mechanics of Prestressing; IV. Details of the Prestressed Concrete Pavement; V. Economy of the Prestressed Concrete Pavements.

B166. Gannett, J. K.; Waidelich, A. T., "Prestressed Concrete in Buildings", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August 1951, pp. 67-86.

This paper discusses the practicality and economy of prestressed concrete for buildings in part I. In part II of the paper are described the tests on bonded and unbonded prestressed concrete girders carried out by the Austin Co. - no test data is given except concerning the behavior of the girders during the test. The paper is followed by discussions by P. F. Blair who described precast, prestressed, concrete girders used in buildings in Oklahoma, and by H. Thorsen who described precast, prestressed concrete girders used in European buildings.

B167. Gooding, "The Prestressed Development Group", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 237-238.

A very short description of the development work done in Great Britain in the field of prestressed concrete.

B168. Harris, J. D., "The Application of Prestressed Concrete to Highways and Bridges", Journal, Institute of Municipal Engineers (London), 1951, Vol. 77, No. 9, pp. 733-758.

Description of shortspan prestressed concrete bridges built in England and of a few long-span bridges built in continental Europe. Description of prestressed concrete slabs for highways.

B169. Hicks, J. N., "Current Developments in Prestressed Concrete", Proceedings of the Second Annual Structural Engineering Conference, Bulletin of the Florida Engineering and Experiment Station 47, pp. 31-35, 1951.

A discussion of the current developments in prestressed concrete which have been made by Roebling's Sons Company. Discussion of the prestressing cables and of their use.

B170. Horel, J., "Napínáni a kotvení předpjaté výztuže prvku dodatečně napinaných", (Prestressing and Anchorages of Pretensioned Elements), Stavební prumysl (Prague), 1951, Vol. 1, No. 15, pp. 346-350.

Description of anchorages of Freyssinet and related types.

B171. Johnson, C. L., "The John R. Bridge", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 61-64.

A short paper augmented with photographs which describes the assembling of prestressed beams using I-shaped elements. These particular beams were used in a bridge in Oakland Company, Michigan. One similar 60 ft. girder was tested - its behavior during loading is briefly described.

B172. Klett, E., "Die Spannbetonbrücke der Bundesbahn über den Neckarkanal in Heilbrann", Beton-und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 7, pp. 145-150; No. 8, pp. 180-184.

Description of prestressed concrete railway bridge over Neckar canal in Heilbrann. Bridge is composed of continuous girders Prestress wires were wrapped around massive concrete blocks which were jacked apart for prestressing the wires. Two small beams which were tested are discussed.

B173. Korvas, A., "Výrobní a připravné problémy při prefabrikaci, těžké, montáži a při předpínání betonu", (Problems of manufacture for precasting, heavy erection and prestressing of concrete), Stavební prumysl (Prague), 1951, Vol. 1, No. 14, pp 329-335.

One part of this paper is devoted to the discussion of manufacture of post-tensioned concrete elements. Special attention is paid to the problems connected with the manufacture of end blocks. to the methods of making the cable openings, and to prestressing

B174. Leduc; Gapillout, "Usine Boneuil," Travaux (Paris) 1951, Vol. 35, No. 196, pp 213-214.

Methods of manufacture of prestressed, precast, small beams and railway ties. Relative costs also discussed

B175. Magnel, G., "Revolutionary Staircase Built of Prestressed Concrete", Civil Engineering, 1951, Vol. 21, No. 9, pp. 505-507.

Description of helical staircase built of prestressed concrete in Antwerp. Short summary of the design and description of the tests of a full-scale model built at the University of Ghent.

B176. Mass, M. L.; Janney, J. R., "Simple Equipment Economically Explores Prestressing", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 5, pp. 361-364.

Description of a simple procedure of prestressing and anchoring the wires suitable for small laboratory research and instruction work.

B177. Middendorf, K. H.; Panhorst, F. W., "The Arroyo Seco Bridge", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 65-66.

A short paper describing the construction of the prestressed concrete girders of the Arroyo Seco Pedestrian Bridge.

B178. Mitchell, S., "Are Prestressed Bridges Cheaper?", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 10, pp. 761-772.

Discussion of the construction and costs of the pedestrian bridge over Arroyo Seco in Los Angeles. High costs of prestressing are pointed out. It is pointed out also that further studies and better specifications are needed to promote the use of prestressed concrete.

B179. Morandi, R., "Sur la réalixation d'ouvrages en béton précontraint", La Ricerca Scientifica (Rome), 1951, Vol. 21, No. 2, pp. 227-231.

The author describes his method of prestressing and his patented wedging-type anchorage. Several structures built by their method are described.

B180. Neuffer, W., "Stahlbeton im Ausland", Beton-und Stahlbetonbau (Berlin), November, 1951, Vol. 46, No. 10, pp. 217-222; No. 11, pp. 247-253.

This article describes concrete bridges, most of which are prestressed, built in European countries other than Germany.

B181. Nicolle; Muller, J., "Parking souterrain," Travaux, (Paris), 1951, Vol. 35, No. 196, pp. 218-219.

Description of underground parking garage under construction. Precast and prestressed beams.

B182. Parrett, J. J., "First Prestressed Piles Carry Tank Platform", Engineering News Record, July 5, 1951, Vol. 147, No. 1, pp. 38-39.

Description of construction of concrete piles prestressed at 8 points along the circumference. Prestress accomplished by Freyssinet method. All wires grouted in and piles cut-off after hardening of the grout.

B183. Pauw, A.; Reid, R. L., "Lightweight Prefabricated Joist-Slab-Beams of Prestressed Concrete", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 247-252.

This paper discusses the problems encountered in the production of small precast prestressed concrete members. Economy, materials, anchorage, and bond are discussed. Tests made to solve some of these problems are discussed.

B184. Philippi, "Les supports caténaires en béton précontraint sur la ligne électrifiée Paris-Lyon", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 233-235.

This article describes the prestressed concrete poles which are used to support the electric lines along the railroad Paris-Lyon. The poles are trussed and precast. The precasting and prestressing operations are explained.

B185. Stepanek, V., "Konstrukce předem napínané - konstrukční a výrobní zkušenosti", (Pre-tensioned Structures - Experiences from Construction and Manufacture), Stavební prumysl (Prague), 1951, Vol. 1, No. 15, pp. 353-357.

Discussion of the merits and disadvantages of longline and individual unit processes.

B186. Stöhr, W., "Die neue Kanalhafenbrücke in Heilbronn", Beton-und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 2, pp. 30-32

Description of a prestressed arch bridge over the canal in Heilbronn. End anchored cables, grouted for bond were used for prestressing.

B187. Storrer, "Le pont de Sclayn a Namur", Travaux (Paris) 1951, Vol. 35, No. 196, pp. 242-243.

Description of a two span continuous bridge in Belgium prestressed by the Magnel-Blaton system. Dimensions of the structure and quantities of materials are given.

B188. Vallette, R., "Emploi du fil a haute limite élastique et réglage des contraintes dans les constructions", Annales de L'Institut Technique de Batiment et des Travaux Publics. New Series, Theories and Methods of Design No. 14, 1951

The author advances the idea that prestressing is a means of utilizing high strength wire without danger of excessive deflections. He gives examples of parabolic shaped prestressed concrete beams and trusses which would require the minimum amount of materials.

B189. Vasseur; Schere, "Reconstruction du hangar 1 du quai de la Garonne, dit 'Hangar aux Contons'", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 225-226.

Description of the reconstruction of a hangar damage during the war. Prestressed concrete used in order to have a fireproof structure.

B190. Voss, W. C., "Prestressed Units", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 253.

This paper discusses the manufacture of precast prestressed units with respect to economy and efficiency.

B191. Zollman, C. C., "Survey of European Prestressed Concrete Bridge Construction", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 30-46.

A description of several large prestressed concrete bridges. The dimensions of spans, and cross-sections augmented with photographs are given. Construction techniques are discussed. Reasons for economy are discussed.

B192. - - -, "A Continuous Concrete Bridge in France", Concrete and Constructional Engineering (London), 1951, Vol. 46, No. 1, pp. 1-27.

The construction and design of this bridge is explained in this article. The beams are precast and prestressed to carry their own weight on the ground. After being placed on the piers, the beams are further prestressed in such a manner that they act as one continuous beam instead of 3 spans of simple beams.

B193. - - -, "Bridge Built of Blocks Strung Like Beads," Engineering News Record, January 18, 1951, Vol. 146, No. 3, pp. 39-42.

Description of the development of prestressed concrete block beams by Bryan and Dozier in Nashville, Tenn. Construction of a three simple span bridge and a football stadium made of such beams is described.

B194. - - -, "Cast-in-place Concrete Bridge Beams Prestressed", Engineering News Record, December 13, 1951, Vol. 147, No 24, p. 42.

Short description of prestressed concrete bridge under construction in Austin County, Texas.

B195. - - -, "Concrete Prestressed in Tension", Engineering News Record, May 3, 1951, Vol. 146, No. 18, p. 33.

K. Billig's suggestion for relief of high compression in concrete columns and arches by embedding a steel strut precompressed by a steel cable.

B196. - - -, "Construction of a Road in Prestressed Concrete", Civil Engineering and Public Works Review (London), 1951, Vol. 46, No. 538, pp. 254-255.

400 ft. of highway was constructed of prestressed concrete at Crawley, in Sussex, in order to study the feasibility of prestressed concrete roads. Strain measurements and behavior will be observed over a period of several months. Freyssinet cables were used. Construction procedure was described. Advantages are listed as: (a) elimination of cracks; (b) reduction in number of expansion joints; (c) improvements in riding; (d) low maintenance.

Disadvantages are listed as: (a) difficulty in reinstating when one part is removed for some reason; (b) complicated nature of expansion joints.

B197. - - -, "India Begins Construction of its First Prestressed Concrete Road Bridge", Engineering News Record, December 13, 1951, Vol. 147, No. 24, pp. 51-52.

Short description of a road bridge in Madras State. The bridge will have 23 spans, beams will be prestressed by the Magnel-Blaton system. One of the beams will be tested to destruction.

B198. - - -, "New Idea for Prestressing Concrete, Apply Prestress with Glass", Engineering News Record, March 1, 1951, Vol 146, No. 9, p. 45.

Prestressing with glass fibres is discussed. This method is suggested by Professor I. A. Rubinsky of the American University in Beirut, Lebanon.

B199. - - -, "Novel Prestress Design for Office Building", Engineering News Record, October 18, 1951, Vol. 147, No 16, p. 38

Discussion of a factory floor with prestressed girders and beams with a slab of ordinary reinforced concrete. The structure was in part precast and in part cast in place.

B200. - - -, "Plant for Prestressing Concrete", Ministry of Works (London), National Building Studies Bulletin No 12, 1951, (H. M. Stationary Office)

This bulletin is of principle interest because of its descriptive photographs of anchorages for wires. Also described is the method of manufacture used by Ministry of Works in England.

B201. - - -, "Prestressed Block Beams Span 43 ft.", Engineering News Record, October 25, 1951, Vol. 147, No. 17, pp. 30-31.

Description of the manufacture of prestressed concrete bridge beams made up of precast concrete blocks in Detroit, Michigan.

B202. - - -, "Prestressed Concrete Footbridge at Oxford," Builder (London), 1951, Vol. 180, No. 5632, pp. 131-133.

Brief description of a fixed arch footbridge at Oxford prestressed by Freyssinet system.

B203. - - -, "Prestressed Concrete Road at Crawley", Concrete and Constructional Engineering (London), 1951, Vol. 46, No. 5, pp. 147-149.

Description of the construction of a 400-ft. strip of roadway built of prestressed concrete in England. Roadway is prestressed by Freyssinet cables.

B204. - - -, "Prestressed Concrete Warehouse", Concrete and Constructional Engineering(London), 1951, Vol. 46, No. 3, pp. 92-93.

Brief description of the construction of a warehouse for H. M. Stationary Office in England. Floors and roofs of this building were built of prestressed, precast concrete beams. Prestressing by Magnel's system.

B205. - - -, "Prestressed Roof Beams Get First U. S. Tryout", Engineering News Record, October 25, 1951, Vol. 147, No. 17, p. 32.

Description of two factory roofs built with prestressed concrete beams in Tulsa, Oklahoma.

B206. - - -, "Repair of an Arch Bridge with Expanding Cement", Concrete and Constructional Engineering (London), 1951, Vol. 46, No. 4, pp. 119-121.

Paper describes the procedure of using expanding cement for repair of an arch damaged by settlement of one pier. Repair was designed by Lossier.

B207. - - -, "Rigid Frame Bridge on Prestressed Concrete", Engineering News Record, March 15, 1951, Vol. 146, No. 11, p. 35.

Brief description of the footbridge over a branch of the Cherwell River in Oxford, England.

B208. - - -, "Road Prestressed to Prevent Cracks", Engineering News Record, April 12, 1951, Vol. 146, No. 15, p. 37.

400 ft. of roadway in England is prestressed as an experiment. Expected results are prevention of cracks, reduced number of expansion

joints, improve riding quality, lower maintenance costs. Construction procedure and prestressing method is given.

B209. - - -, "Simple Prestressing System for Pedestrian Bridge", Engineering News Record, May 10, 1951, Vol. 146, No. 19, pp. 40-41.

This article is concerned with the pedestrian bridge over the Arroyo Seco in Los Angeles. Prestressing was done according to Prestressed Concrete Corporation of Kansas City. Five wires stretched at a time. Consists of 2 girders 110 ft. long by 5'-8" deep I-sections. Prestressing technique, including difficulties encountered, is given. Button-heads were put on end of wire.

B210. - - -, "The Festival Exhibition Footbridges", Civil Engineering and Public Works Review (London), 1951, Vol. 46, No. 539, pp. 346-348.

Several pedestrian bridges have been built on the sight of the Festival of Britain. One such bridge is of prestressed concrete. The one single main beam supports a slab (cantilevered on both sides) about 12 ft. wide. The bridge is continuous and length of spans vary from 54 ft. to 76 ft. Freyssinet cables were used.

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A4, A9, A18, A27, A65, A107, C2, C9, C11, C20, C24, C27, C30, C51, D72, D74, D80, D81, D90, D94, D101, E44.

C. Design

1938

C1. Kilgus, E. M., "Möglichkeiten des Eiseneinsparens", Zement (Berlin), 1938, No. 23, pp. 26-28.

Prestressed hollow concrete mast is compared with one made of ordinary reinforced concrete and it is shown that the prestressed mast is more economical in the amount of steel needed.

1939

C2. Hoyer, E., "Der Stahlsaitenbeton", Band I, Träger und Platten, Berlin-Wien-Leipzig, 1939, (Otto Elsner Verlagsgeselschaft).

This book is divided into three chapters: First, general chapter is a discussion of the prestressed concrete in comparison with an ordinary reinforced concrete, description of materials suitable for prestressed concrete. Both pre- and post-tensioned types are mentioned. Hoyer stresses the increase of the cracking load. The second chapter deals with the design of pretensioned members. The third is a description of the manufacture of pretensioned concrete members. The fourth chapter is a report of 8 series of tests all on pretensioned beams or related problems:

> 1. beam tests; 2. beam tests; 3. beam and floor tests; 4. bond tests; 5. beam tests; 6. beam tests - effect of age; 7. sustain-load tests of steel; 8. fatigue tests of beams.

1941

C3. Fornerod, M., "Factors in Prestressed Girder Design", Proceedings, American Concrete Institute, 1941, Vol. 47, No. 6, pp. 469-480.

Discussion of a design theory in relation to the Walnut Lane Bridge. With the exception of the span length and the external load, the most important factors in the design are the ratio of the L. L. to D.L., shape of cross section, method of prestressing and erection, and the total allowance for the losses of prestress. Brief mention of the test of the Walnut Lane Bridge girder.

1942

C4. Bertin, R. L., "Saving Steel in Reinforced Concrete", Proceedings, American Concrete Institute, 1942, Vol. 38, No. 4, pp. 281-288.

In discussion of this paper concerned with economy in the use of reinforcement Shorer and Kauf point out the feasability of saving steel by use of prestressed concrete.

1943

C5. Billig, K., "Prestressed Reinforced Concrete", Jamaica, New York, 1943, (F. Billig).

General discussion of the developments and various methods of prestressing. Section on tests gives only incomplete information. Design theory for tension and flexural members is given.

1944

C6. Guyon, Y., "Poutres et dalles précontraintes", Institut Technique du Batiment et des Travaux Publics (Paris), Circulaire Serie J, No. 3, 1944.

Design of flexural members dealt with at length. Resistance to shear discussed and examples worked out. Both cables and individual wires considered.

1945

C7. Abeles, P. W., "Fully and Partly Prestressed Reinforced Concrete", Proceedings, American Concrete Institute, 1945, Vol 41 No. 3, pp. 181-214.

A discussion of tests conducted by others. A history of development of prestressed concrete. Relative merits of full and partial prestressing where cracks are objectionable or where maximum design load is very infrequent.

C8. Guyon, Y., "Etude sur les poutres continues et sur certains systèmes hyperstatiques en béton précontraint", Institut Technique du Batiment et des Travaux Publics, Circulaire Serie J, No 8, Paris, 1945.

The paper deals with the design of continuous beams and frames of prestressed concrete. Particular attention is given to finding the eccentricity of the prestressing cables for all points along the beam Examples included.

1946

C9. Abeles, P. W., "Beams in Prestressed Reinforced Concrete", Concrete and Constructional Engineering (London), 1946, Vol. 41, Nos. 6-8, pp. 147-154, 191-199, 225-230.

Description of the behavior of prestressed concrete beams at low loads. Working stress design formulas given. Description of prestressed members of existing bridges. Most of the material the same as in Abeles' book "Principles and Practices of Prestressed Concrete".

C10. Magnel, G., "Béton précontraint", Annales des Travaux Publics de Belgique, April, 1946.

This article is concerned with the design of simply supported flexural members. Methods of analysis and examples are given. Beams of variable moment of inertia are discussed. Much of this material is in Magnel's book.

C11. Pacholik, L., "Konstrukce c predpjateho betonu", (Prestressed concrete structures), Series "Konstrukter" No. 22, Prague 1946, (Publisher Gregr).

Description of the basic principles of prestressed concrete, design theory and examples, construction procedures and examples of existing structures.

C12. Schorer, H., "Analysis and Design of Elementary Prestressed Concrete Members", Proceedings, American Concrete Institute, 1946, Vol. 43, No. 1, pp. 49-87.

A fairly complete derivation of formulas required for the design of simply supported members of prestressed concrete. Also formulas for ultimate resisting moment. Examples given.

1947

C13. Weinberg, V., "Le béton précontraint", Paris (Dunod, 92 Rue Bonaparte) 1947.

This book deals mostly with methods of design. Some discussion of the behavior and characteristics of prestressed concrete and materials thereof is added. Several design examples are included.

C14. - - -, "Road Bridge Design", The Reinforced Concrete Review, (London), Vol. 1, No. 7, pp. 205-206, 1947.

Abstract of a paper by J. E. Jones in which comparison was made between prestressed concrete slab bridges and similar bridges in reinforced concrete.

1948

C15. Abeles, P. W., "Examples of the Design of Prestressed Concrete Beams", Concrete and Constructional Engineering (London), 1948, Vol. 43, No. 5, p. 149.

Method of section design with examples. Discussion of prestressing the continuous beams - the present design of continuous beam is considered inadequate.

C16. Abeles, P. W., "The Behavior of Prestressed Concrete at Cracking", Int. Assoc. Bridge and Struct. Eng., Third Congress, Final Report, Liege 1948, pp. 373-378.

Discussion of the allowable stresses with reference to the cracking characteristics of prestressed concrete beams. Based on British and Swiss tests.

C17. Abeles, P. W., "The Economy of Prestressed Concrete", Int. Assoc. Bridge and Struct. Eng., Third Congress, Final Report, Liege 1948, pp. 373-378.

A comparative study based on conditions in Great Britain. Full prestress vs. partial prestress. Prestress vs. steel. Favors partial prestress.

C18. Barets, T., "Method pour la determination rapids des diagrammes d'efforts tranchants reduits optima dans le poutres en béton précontraint a cables releves", Travaux (Paris), 1948, Vol. 32, No. 168, pp. 541-544.

A graphical method for determination of optimum spacing for curved-up cables in prestressed concrete beams.

C19. Billig, K., "A Proposal for a Draft Code of Practice for Prestressed Reinforced Concrete", (P.R.C.), London 1948.

A tentative proposal of specifications published as a phamphlet.

C20. Magnel, G., "Béton précontraint", French Edition, Ghent 1948 (published by Fecheyer). First English Edition, London 1948, (Concrete Publications Limited), Second English Edition London 1950.

General reference concerned primarily with beams. A large portion of this book is devoted to Magnel's tests.

C21. Abeles, P. W., "Principles and Practices of Prestressed Concrete", British Edition 1948, American Edition (Ungar Publ. Co.) New York 1949.

This book deals mainly with prestressed concrete beams.

1949

C22. Baker, A. L. L., "Reinforced Concrete", London 1949, (Concrete Publications Ltd.).

Chapter VI on pp. 165-196 deals with prestressed concrete; partly general discussion of the principles involved, but largly with design on the basis of working loads.

C23. Billig, K., "The Ultimate Load and Factor of Safety of Prestressed Concrete", Civil Engineering and Public Works Review (London), 1949, Vol. 44, No. 520, pp. 579-581
No. 521, pp. 651-654
No. 522, pp. 721-723
1950, Vol. 45, No. 523, pp. 39-40

Design procedure based on Bernoulli's hypothesis, statics, and stress-strain diagrams for steel and concrete. Numerical values computed for a pole are compared with the test results.

C24. Dischinger, F., "Stahlbrücken im Verbund mit Stahlbetondruckplatten bei gleichzeitiger Vorspannung durch hochwertige Seile," Der Bauingenieur (Berlin), 1949, Vol. 24, Nos. 11-12, pp. 321-332, 364-376.

This paper deals with the subject of prestressing composite steel and concrete girder bridges. Typical examples of stress analysis under various conditions are given. The Dischinger-Finsterwalder method of prestressing.

1950

C25. Baker, A. L. L., "A Plastic Design Theory for Reinforced and Prestressed Concrete Shell Roofs", Magazine of Concrete Research (London), 1950, Vol. 2, No. 4, pp. 27-34.

A theory is proposed which provides a simple method for designing shell roofs, including prestressed shells. This method takes into account the plasticity and cracking of the concrete as the ultimate load is approached. The possible limits of shear stress distribution across a transverse section are considered and it is shown that the bending moment does not vary greatly between these limits. The theory is intended as a basis for experimental work to be done in the near future at Imperial College, London.

C26. Balaca, A. P., "Dimensionamientos anelasticos en hormigón pretensado", Informes de la Construction (Madrid), October, 1950, Vol. 3, No. 24, Section 457-1, pp. 1-7

Ultimate design of prestressed concrete beams.

C27. Bruggeling, A.S.G.; Hartman, J.A.H.; Meischke, J. C., "Voorgespannen Beton", 1950, Uitgeverij Waltman, pp. 268.

This book would be of interest to both students and designing engineers. The book contains the general and basic concepts of prestressed concrete, methods of prestressing and fabrication, properties of materials, a large section on design and analysis, and a section on description of structures built.

C28. King, J. W. H., "The Design of Prestressed Concrete Beams from Fundamental Principles", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 9, pp. 307-319.

Outline of principles for design of prestressed concrete beams. This design is based on Bernoulli's hypothesis, statics, and stress-strain diagrams for steel and concrete. Pre-tensioned and post-tensioned (both bonded and unbonded) types are discussed. Numerical examples are given.

C29. Lämmlein, A., "Ueber the Wirtschaftlichkeit von Spannbeton-Strassen-Brücken", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 3, pp. 66-68.

Economic comparative study of a highway bridge design in prestressed and reinforced concrete. The prestressed concrete bridge was more economical both in quantities of materials and overall costs. The prestressed structure was built.

C30. Magnel, G., "Prestressed Concrete", London 1948 (Concrete Publications Ltd.), Second Edition, London 1950.

English edition of the book Béton précontraint by the same author.

C31. Rüsch, H., "Erläuterungen zu den Richtlinien für die Bemessung vorgespannter Sthalbetonbauteile", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 5, pp. 108-116.

Explanations to the German specifications (1950) for prestressed concrete.

C32. Silvera, V. M., "A Method of Design for Shell Concrete Roofs Using Prestressed Edge Beams", Magazine of Concrete Research (London), 1950, Vol. 2, No. 4, pp. 9-14.

Design theory described.

C33. Uziel, F. J., "Determining Optimum Cross Section for Prestressed Concrete Girders", Proceedings American Concrete Institute, 1950, Vol. 47, No. 3, pp. 197-212

Formulas for the design of simply supported prestressed concrete girders, based on allowable stresses.

C34. - - -, "Vorgespannte Stahlbetonbauteile, Richtlinien für die Bemessung", Beton und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 4, pp. 80-90.

German tentative specifications for prestressed concrete.

1951

C35. Abeles, P. W., "The Ultimate Resistance of Prestressed Concrete Beams", Concrete and Constructional Engineering (London), 1951, Vol. 46, No. 10, pp. 295-303.

This paper discusses ultimate failures of prestressed concrete beams and offers design formulas for bonded and unbonded cases of rectangular and I-sections.

C36. Billig, K., "Pretensioned Concrete", Civil Engineering and Public Works Review (London), 1951, Vol. 46, Nos. 536, 537, pp. 96-98, 181-182.

A method is suggested for pre-tensioning compression members such as columns and arches in order to reduce the dead load.

C37. Billner, K. P., "Economical Cross Section of Prestressed I-Beams and Box Girders Determined Graphically", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 7, pp. 565-567, Letters from Readers Section.

A trial and error design method. Tension is not permitted in the concrete.

C38. Bjuggren, Ulf, "The Ultimate Bending Strength of Bonded Prestressed Concrete", Congrès International du Béton Précontraint, Communication No. B-10, 1951.

This paper presents an ultimate design theory for bonded prestressed concrete beams. The method incorporates a factor of safety of 1.2 against cracking and 2.5 against bending failure. It is used in design of beams at AB Betong industri's factory in Stockholm.

C39. Brown, V. J., "How to Design a Prestressed Concrete Tee Beam", Roads and Streets, June, 1951, Vol. 94, No. 6, pp. 47-54.

This paper goes through step-by-step the design of T-beam girders of 75 ft. span for a bridge over the Rio Grande River in New Mexico. The design was made by engineers of the John A. Roebling's Sons Co. and features the Roebling cable and end anchorages.

C40. Bruggeling, A.S.G., "Coefficients pour dimensionner les constructions en beton précontraint, Constructions Isostatiques", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 247-253.

Set of tables for the design of I- and T-beams.

C41. Channey, D. L., "Design of Prestressed Concrete", Proceedings of the Second Annual Structural Engineering Conference, Bulletin of the Florida Engineering Experiment Station 47, 1951, pp. 22-26.

Fundamental principles of the design of prestressed concrete sections.

C42. Coff, L., "Fine Wires Uneconomical", Engineering News Record, May 24, 1951, Vol. 146, No. 21, p. 47. Reader Comment Section.

Discussion of Abeles' paper ENR April 12, p. 42. Coff suggests that cables are more logical and economical for the American practice.

C43. Coff, L., "Prestressed Roads Favored", Engineering News Record, June 28, 1951, Vol. 146, No. 26, p. 46. Reader Comment Section.

In this discussion of the paper "Roads prestressed to prevent cracks" (ENR April 12, 1951, p. 37) it is pointed out that crackless roadways of prestressed concrete might be an acceptable solution in spite of the higher initial costs.

C44. Devis, C. E., "Prestressed Concrete: Outline of Design for Bending Stresses", Magazine of Concrete Research (London), 1951, No. 6, pp. 123-126.

Design procedure for beams. It is recommended to use a rectangular section as a preliminary guide for the design. Simple expressions for losses of prestress. Nothing new.

C45. Feld, J., "Watchmaking Prestressing", Engineering News Record, October 11, 1951, Vol. 147, No. 15, pp. 48-51. Reader Comment Section.

General comments to the First US Conference on Prestressed Concrete. The author expresses his opinion that prestressing methods of the present day are too costly for the American market.

C46. Fornerod, M., "General Design and Economic Considerations in the Planning of Prestressed Concrete Structures", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 178-185.

This paper presents a broad outline of the problems connected with prestressed concrete. The paper is discussed with W. E. Dean of Florida Bridge Dept. with respect to factor of safety and cost.

C47. Freyssinet; Magnel; Lardy; Lossier; Baker; Abeles; Lee; Singleton-Green, "Notation for Prestressed Concrete", Concrete and Constructional Engineering (London), 1951, Vol. 46, No. 2, pp. 61-63.

Each of the authors states his views in a separate paragraph on the desirability and chance of establishing an international standard notation for prestressed concrete design. Most authors agree that such notation would be desirable but impossible; no such standardization was ever achieved even for reinforced concrete.

C48. Germundsson, T., "Prestressed Concrete Design Concepts", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 186-194.

This paper outlines the steps encountered in designing a girder and works through a design problem for illustration. Behavior at various states of loading is discussed. The paper is discussed by the late Dean Peabody who briefly discusses working stresses and design methods.

C49. Hadley, H. M., "Why Prestress?", Engineering News Record, December 20, 1951, Vol. 147, No. 25, p. 11. Reader Comment Section.

Short discussion of Feld's letter (ENR October 11, 1951, p. 49) in which Hadley concurs with the opinion that present methods of prestressing are too expensive.

C50. King, J.W.H., "A Fundamental Approach to Prestressed Concrete Design", The Structural Engineer (London), 1951, Vol. 29, No. 1, pp. 12-20.

A design procedure based on the flexure formula. All that is necessary is to know the stress-strain properties of the concrete and of the steel. Examples are worked for illustration.

C51. Kirkland, C.W.; Goldstein, A., "The Design and Construction of a Large Span Prestressed Concrete Shell Roof", The Structural Engineer (London), 1951, Vol. 29, No. 4, pp. 107-127.

Description of the design problems and procedures and of the construction of a large garage in England.

C52. Lazarides, T. O., "The Use of Unstressed Wires in Pretensioned Concrete Members", Magazine of Concrete Research (London), 1951, Vol. 2, No. 6, pp. 119-122.

In the serial fabrication of pre-tensioned wires odd lengths of wire are left over. These odd lengths may be used effectively as additional unstressed reinforcement on the compression side to prevent danger of breaking the beams during handling or as stirrups.

C53. Mahler, M., "Whither Prestressing?", Engineering News Record, December 27, 1951, Vol. 147, No. 26, p. 7, Reader Comment Section.

Discussion of letters by Feld (Eng., October 11, p. 48) and by Winter (ENR, Nov. 1, p. 65) in which Mahler advances the opinion

that there is nothing wrong with using European techniques at first. He also advocates teaching of prestressed concrete as a separate subject.

C54. Parme, A. L.; Paris, G. H., "Analysis of Continuous Prestressed Concrete Structures", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 195-206.

This paper deals with the analysis of continuous members of prestressed concrete. Particular attention is given to beams with continuous curved cables, discontinuous straight cables, curved and straight haunches. Tables are given for finding the moments for these various conditions.

C55. Parme, A.L.; Paris, G.H., "Designing for Continuity in Prestressed Concrete Structures", Proceedings, American Concrete Institute, 1951, Vol. 48, No. 1, pp. 45-64.

Outline of a design procedure for continuous prestressed concrete beams with numerical examples. Design is based on working loads, but factor of safety against the ultimate capacity of the design section is also considered.

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A-4, A-75, A-76, A-78, B-80, B-99, D-14, D-39, D-67, D-70, D-85, D-90, D-93.

D. Miscellaneous

1907-1933

D1. Koenen, M., "Wie kann die Anwendung des Eisenbetones in der Eisenbahnverwaltung wesentlich gefordert werden", Zentralblatt der Bauverwaltung (Berlin), September 28, 1907, Vol. 27, No. 79, pp. 520-522.

Koenen suggests that the cracking load of a reinforced concrete beam may be increased by pretensioning the reinforcing bars. The paper contains a scheme for pretensioning (a similar scheme was used later by Bach and Graf) and gives an example of calculating the stresses before cracking.

D2. Polivka, J. J., "Wettsteinove betonové desky (prkna)", Technická encyklopedie, Vol. 15, pp. 335-336, Prague, 1933. English translation in ACI Proceedings Vol. 46, pp. 724-4--724-5, 1950.

Description of prestressed concrete planks pretensioned with piano wire. Manufacture began around 1920.

1935

D3. Freyssinet, E., "Progres pratique des methodes de traitment mécanique des bétons", Travaux (Paris), 1935, Vol. 19, No. 30, pp. 199-210.

General discussion of prestressed concrete. Detailed descriptions of some of his structures.

D4. Freyssinet, E., "Une révolution dans les techniques de béton", Bulletin de la Societe des Ingenieurs Civils, Paris, 1935, pp. 643-674.

Freyssinet's theory of molecular attraction; an attempt to explain shrinkage and creep of concrete is discussed at length. The process and advantages of prestressing are described. Tests of prestressed concrete masts are compared with the results of tests of masts of ordinary reinforced concrete. Description of various applications of prestressed concrete.

1936

D5. Freyssinet, E., "A Revolution in the Technique of the Utilization of Concrete", The Structural Engineer (London), 1936, Vol. 14, No. 5, pp. 242-262.

This is the same material as in the paper "Une révolution dans les techniques de béton" Paris 1935.

D6. Freyssinet, E., "Practical Improvements in the Mechanical Treatment of Concrete", Int. Assoc. Bridge and Struct. Eng., Second Congress, Preliminary Publication, Berlin 1936 (W. Ernst), pp. 197-222.

Similar to "A Revolution in the Technique of Utilization of Concrete", except that it does not include his theory of hardening of concrete.

D7. Lossier, H., "Les fissures du beton arme", Genie Civil (Paris), 1936, Vol. 108, No. 8-9, pp. 182-186, 202-206.

Discussion of the cracking of reinforced concrete. Explanation of the principles of prestressed concrete and examples of various structures built of prestressed concrete. Discussion of the possibilities of the use of expanding cements as the prestressing medium and mention of the tests made with these cements.

D8. Mautner, K. W., "Spannbeton nach dem Freyssinet-Verfahren", Beton und Eisen (Berlin), 1936, Vol. 35, No. 19, pp. 320-324.

Discussion of the basic principles and advantages of prestressed concrete. Discussion of the test of a prestressed concrete I-beam (same as reported by Opperman in 1940 in more detail) and of tests of prestressed concrete pipes.

D9. Mautner, K. W., "The Elimination of Tension in Concrete and the Use of High Tensile Steel by the Freyssinet Method", Int. Assoc. Bridge and Struct. Eng., Second Congress, Final Report, Berlin 1936, (W. Ernst).

Brief review of Freyssinet's work in prestressing. Discussion of the necessity of using the high strength wire. It is argued that a lower factor of safety may be used for prestressing than for ordinary concrete work as prestressed concrete is free of cracks.

D10. Paris, A., "Mise en tension préalable des armatures du béton armé, son principle, son calcul, ses application", Bulletin Technique de la Suisse Romande (Lausanne), 1936, Vol. 62, No. 25, p. 303.

A preview of an article published by the same author and magazine a year later: "Mise en tension préable des armatures du béton armé".

D11. - - -, "Une revolution dans les techniques du beton", Travaux (Paris), 1936, Vol. 20, No. 37, p. 17.

This is a resumé of the paper "Une révolution dans les techniques de béton" by E. Freyssinet (Paris 1935).

1937

D12. Kuhn, R., "Ein beachtenswerter Fortschritt im Eisenbetonbau", Die Bautechnik (Berlin), 1937, Vol. 15, No. 55, p. 738.

Short description of the basic idea of prestressed concrete and of a few works by Freyssinet and others.

D13. Lenk, K., "Herstellung und Anwendung von Spannbeton", Beton und Eisen (Berlin), 1937, Vol. 36, No. 10, pp. 161-169.

Short historical review. Description of basic principles. Manufacturing of high quality concrete discussed. Description of a test of an I-beam (same test described better by Opperman in 1940). Examples of use of prestressed concrete for pipes and beams cited. Short discussion of this paper by H. Craemer in dtto, Vol. 36, 1937, No. 18, pp. 303-304 and reply by Lenk on p. 304.

D14. Paris, A., "Mise en tension preable des armatures du béton armé", Bulletin Technique de la Suisse Romande (Lausanne), 1937 Vol. 63, No. 1-3, pp. 2-6, 14-16, 28-34.

First part is devoted primarily to the methods of prestressing, second part to the technology of high strength concrete and third to the design principles and uses of prestressed concrete.

1938

D15. Friedrich, E., "Stahlseitenbetonträger in Hochbau", Deutsche Bauzeitung, 1938, Vol. 72, No. 39, pp. 1065-1068.

Describes some of beams built by Hoyer in Germany. Materials, method of prestressing and some tests are discussed briefly.

D16. Rosov, I. A., "Prestressed Reinforced Concrete and its Possibilities for Bridge Construction", Transactions, American Society of Civil Engineers, 1938, Vol. 103, pp. 1334-1365.

A fairly complete discussion of prestressed concrete simply supported flexural members. Formulas and design examples included. Especially interesting are the discussions by several prominent engineers who expressed their doubt as to the practicability of prestressed concrete.

D17. - - -, "Stahlseitenbeton", Schweizerische Bauzeitung (Zurich), 1938, Vol. 112, No. 8, p. 91.

Short summary of a report given by E. Hoyer at the convention of "die Deutsche Akademie für Bauforschung" in Munster (Germany) July 15-17, 1938. General description of pretensioned beams. Wire 0.5 to 3.0 mm., yield point 24000 kg/sq. cm.

1939

D18. Floris, A., "Steel String Concrete", Engineering News Record, August 3, 1939, Vol. 123, No. 5, p. 135.

Short elementary description of the behavior of prestressed concrete flexural members of Hoyer system.

D19. Kleinlogel, A., "Der Stahlseitenbeton System Hoyer", Beton und Eisen, (Berlin), 1939, Vol. 38, No. 8, pp. 141-147.

This paper gives a brief historical review of the European work on prestressed concrete and describes Hoyer's system. Tests, described in more detail in Hoyer's book, are summarized. The method of prestressing and the manufacturing process are described.

D20. - - -, "Recent Discussions of the Prestressing of Reinforced Concrete, Report of Committee on Masonry", Proceedings, American Railway Engineering Association, 1939, Vol. 40, pp. 431-432.

Very brief article which attempts to tell what prestressing concrete is; its advantages, purposes, etc. It also reviews some literature current to the time.

1940

D21. Emperger, F. v., "Ziel und Zweck der Vorspannung im Eisenbetonbau", Die Bautechnik (Berlin), 1940, Vol. 18, Nos. 22-23, pp. 253-255.

Emperger considers the elimination of cracking as the primary task of prestressing. An example is given in this paper which illustrates saving of steel by adding few prestressed wires to a beam of ordinary reinforced concrete. Problems of simplified prestressing techniques are discussed shortly.

D22. Friedrich, E., "Die Verwandung von hochwertigen Baustählen und die Wege zur Eisenersparniss im Eisenbetonbau", Beton und Eisen (Berlin), 1940, Vol. 39, No. 1, pp. 11-16.

One short paragraph in this paper deals with prestressed concrete construction. It includes some historical information and reasons for use of high strength steel in prestressed concrete.

D23. Gueritte, T J., "Development of Prestressed Concrete - Economy in the Use of Steel", Civil Engineering and Public Works Review (London), 1940, Vol. 35, No 409, pp. 201-204.

Basic theory and advantages of prestressed concrete Long line manufacturing process. Test of one beam from the long line process - complete test procedure given, but data on the properties of materials incomplete. Savings of materials discussed briefly.

D24. Gueritte, T. J., "Recent Developments of Prestressed Concrete Construction with Resulting Economy in Use of Steel", Structural Engineer (London), 1940, Vol. 18, No. 7, pp. 626-642.

Short resume of Freyssinet's work. Description of manufacture of precast and cast in place beams. Test of one beam described. Mautner's appendix on design.

D25. Pistor, "Die Anwendung von Vorspannungen im Stahlbetonbau", Beton und Eisen (Berlin), 1940, Vol. 39, No. 11, pp. 150-154.

Discussion of the general behavior and basic principles of prestressed concrete. Description of various systems of prestressing, particularly of that advocated by Dischinger and Finsterwalder. Description of few structures.

1941

D26. Billig, K., "Prestressed Reinforced Concrete", Transaction, Institute of Civil Engineers of Ireland (Dublin), 1941, Vol. 68, pp. 33-90.

The author discusses briefly the cracking of reinforced concrete and the early attempts of preventing the cracking by prestressing. Short discussion of losses of prestress is followed by rather detailed description of various existing methods of prestressing. Short chapters are devoted to the description of existing structures and to discussion of tests. A rather lengthy part of the paper deals with shell structures. The paper is broad in scope, interesting and informative.

1942

D27. Campeau, C. E., "Étude du béton avec usage des précontraintes", Revue Trimesstrielle, Canadienne, 1942, Vol. 28, No. 112, pp. 444-460.

General discussion of the progress made in prestressed concrete in America. Design equations given and illustrated on an example. Means of prestressing and anchoring the wires listed. Need for tests discussed.

D28. Dodds, A. K., "Prestressed Concrete," Architect and Building News (London), 1942, Vol. 170, No. 3836, pp. 176-178.

Short discussion of the general subject of prestressed concrete.

D29. Ehlers, "Vom Stahlbeton zum Spannbeton", Der Bauingenieur (Berlin), 1942, Vol. 23, Nos. 40-42, pp. 300-302.

Discussion of the differences between the prestressed and ordinary reinforced concrete based on Freyssinet's paper "Une revolution dans l'art de batir: Les constructions precontraintes," Travaux 1941.

D30. Freyssinet, E., "L'emploi d'armatures précontraintes réglables dans les constructions en béton armé", Genie Civil, (Paris), 1942, Vol. 119, No. 24, p. 298.

Freyssinet reviews the work done by others in the field of prestressed concrete prior to his own work, and claims that he introduced the use of high strength wire to overcome the difficulties caused by creep. This article seems to have been inspired by a brief historical introduction to Lossier's paper "Types des pontes en béton armé avec armatures precontraintes reglabes".

D31. Richart, F. E., "Prestressed Steel in Reinforced Concrete", Proceedings, American Concrete Institute, 1942, Vol. 39, No 2, p. 126. Job Problems and Practice Section.

Richart answers the question regarding the use of prestressed concrete (in light of the knowledge and economic conditions of 1942). Used for tanks and similar structures where prevention of cracking is desirable.

D32. - - -, "Le beton precontraint", Travaux (Paris), 1942, Vol. 26, No. 108, pp. 170-171.

A brief article describing prestressed concrete and its advantages.

D33. - - -, "Prestressed Concrete", Science Library (London) Bibliography Series No. 572, 1942.

This is a list of references on prestressed concrete written between years 1936 and 1940. (All of these references are now included in this card catalogue.).

1943

D34. Abeles, P. W., "Prestressed Reinforced Concrete", Architects' Journal, (London), 1943, Vol. 97, No. 2526, pp 410-411

Short article on merits of partial prestressing.

D35. Evans, R. H., "Recent Developments in Structural Engineering", Engineering (London), 1943, Vol. 155, Nos. 4023-4024, pp. 155-156, 176.

A brief resume of the development of prestressed concrete.

Discussion of creep. Equations are given for principal stresses and factor of safety against cracking is discussed. A comparison of quantities of materials for a prestressed and an ordinary reinforced concrete beams is given.

D36. Freyssinet, E., "Une révolution dans l'art de batir; les constructions précontraints", Genie Civil (Paris), 1943, Vol. 120, No. 8, p. 95.

Freyssinet explains briefly the principle of prestressed concrete.

D37. Hajnal-Kanyi, K., "Prestressed Reinforced Concrete", Architects' Journal (London), 1943, Vol. 97, No. 2519, pp. 300-302.

Very brief resume of early attempts at prestressing. Explanation of elementary theory of prestressed concrete.

D38. Lenk, K., "Die Entwicklung des Spannbetons," Beton und Stahlbetonbau (Berlin), 1943, Vol. 42, Nos. 19-20, pp. 145-50.

Description of the evolution of prestressed concrete from conventional reinforced concrete, listing most of the early attempts made by European investigators. Credits Freyssinet with the actual development into a usable form. A few of the early prestressed concrete structures are described.

D39. Mörsch, E., "Spannbetonträger", Verlag von Konrad Wittwer in Stuttgart, 1943.

This book deals primarily with working load design of rectangular and I-cross sections. Short history and description of tests of two large beams (See Oppermann 1940) are included.

D40. Schorer, H., "Prestressed Concrete Design Principles and Reinforcing Units", Proceedings, American Concrete Institute, 1943, Vol. 39, No. 6, pp. 493-528.

General discussion of the basic concepts and various problems in prestressed concrete. Results of tests of prisms and beams are given in fairly complete form.

D41. Stucky, A., "Le béton précontraint (principes, materiaux et procedes)," Bulletin Technique de la Suisse Romande (Lausanne), 1943, Vol. 69, No. 14, pp. 161-168.

Explanation of the basic principles of prestressed concrete and discussion of such problems as cracking, creep, shrinkage. Description of prestressing methods, discussion of various tests.

1944

D42. Eteve, J., "Le beton précontraint: Technique. Utilisation. Application aux travaux coloniaux", Travaux (Paris), 1944, Vol. 28, No. 131, pp. 127-132, 136.

The author explains the disadvantages of the ordinary reinforced concrete and the theory and advantage of prestressed concrete. Description of several structures is followed by the description of Freyssinet's anchorages and of the pretentioned system without anchorages.

D43. Guyon, Y., "Theorie des poutres et dalles en béton précontraint", Institut Technique du Batiment et des Travaux Publics, Circulaire Series J, No. 1, Paris, 1944.

Discussion of the basic principles of prestressing for beams with constant cross-section. Description of Freyssinet's system of prestressing and of Freyssinet's double-acting jack. Prestressed beams are compared with beams of reinforced concrete and the savings in steel is pointed out.

D44. Murray, V. W., "Postwar Concrete Bridge Design", Roads and Bridges, 1944, Vol. 82, No. 11, pp. 56-57, 88-90.

Discussion of the possibility of using prestressed concrete for bridge construction and brief description of the fundamental principles of prestressing.

1945

D45. Magnel, G., "Prestressed Concrete - Some New Developments", Concrete and Constructional Engineering (London), 1945, Vol. 40, Nos. 11-12, pp. 221-232, 249-254, and 1946, Vol. 41, No. 1, pp. 10-21.

Some examples of comparisons between reinforced and prestressed concrete designs are given. Description of Freyssinet's and Magnel's system of anchorages. Some tests of beams are described and descriptions of several structures are also given. Most of this material is in Magnel's book "Béton Précontraint".

D46. Quintal, R., "La pénurie d'acier et le béton précontraint", Revue Trimesstrielle, Canadienne, 1945, Vol. 31, No. 122, pp. 129-138.

Behavior of concrete reinforced with high strength steel is compared with the behavior of prestressed concrete. Basic design equations are given. Losses of prestress are discussed.

1946

D47. Billig, K., "Prestressed Reinforced Concrete", Reinforced Concrete Association (London), Technical Paper No. 5, 1946.

General description of the history, behavior, prestressing operation and existing structures of prestressed concrete.

D48. Carrier, J. P., "Precompressed Concrete Design", Engineering Journal (Montreal), 1946, Vol. 29, No. 8, pp. 462-6, 466-9, 482.

This paper deals with basic concepts of prestressed concrete design. Discussion of the advantages of prestressed concrete. Example of design. Methods of prestressing. Description of a few structures.

D49. Murray, V. S., "Prestressed Concrete Bridges", Roads and Bridges, 1946, Vol. 84, No. 6, pp. 41-46.

Same material as in Magnel's book. Discussed: principle of prestressing, methods of prestressing, possible uses of prestressing other than beams.

D50. - - -, "Prestressed Concrete", The Builder (London), 1946, Vol. 170, No. 5371, p. 59.

A general, not very complete description of the basic principles of prestressed concrete, methods of prestressing and few examples of uses.

1947

D51. Coff, L., "Prestressed Concrete", American City, New York, 1947, Vol. 62, No. 9, pp. 112-113.

Brief description of the fundamental theory of prestressing. Examples of structures built in Europe. Very general, written for the laymen.

D52. Coff, L., "Prestressed Concrete for Bridges and Slabs" American Association of State Highway Officials, New York City Convention Group Meetings, Papers and Discussions, 1947, Published by AASHO, 1220 National Press Building, Washington 4, D. C., pp. 198-225.

Description of Roebling's developments, some tests and construction of their jointless slab. Gives cost data showing an advantage of using prestressed concrete.

D53. Magnel, G., "The Principles of Prestressed Concrete", Civil Engineering and Public Works Review (London), 1947, Vol. 42, No. 497, pp. 488, 490, 492.

General discussion of prestressed concrete.

D54. Magnel, G., "The Principles of Prestressed Concrete", Engineering Journal (Montreal), 1947, Vol. 30, No. 3, pp. 110-112.

This paper is a resume of several talks given by the author before various branches of the Engineering Institute of Canada in May, 1946.

The author points out the advantages of prestressed concrete, compares the designs of a reinforced and of a prestressed concrete slab bridge. Explanation of the Magnel's method of prestressing and of prestressing with outside cables, and of pretensioning.

1948

D55. Abeles, P. W., "The Development of Prestressed Concrete", Civil Engineering and Public Works Review (London), 1948, Vol. 43,

Part 1: No. 499, pp. 26-29
Part 2: No. 500, pp. 86-90
Part 3: No. 501, pp. 145-150
Part 4: No. 502, pp. 200-206
Part 5: No. 503, pp. 248-251
Part 6: No. 504, pp. 306-312
Part 7: No. 505, pp. 358-364
Part 8: No. 506, pp. 414-418
Part 9: No. 507, pp. 464-470
Part 10: No. 508, pp. 519-524

D56. Armstrong, W.E.I., "Prestressed and Post-stressed Concrete", Surveyor (London), 1948, Vol. 107, No. 2922, pp. 77-78.

Pretensioned and post-tensioned concrete are defined and basic principles of prestressing are explained. The advantages of prestressed concrete over ordinary reinforced concrete are discussed

D57. Elliott, L. W., "Recent Development in Prestressed Concrete", The Builder, (London), 1948, Vol. 175, No. 5520, pp. 659-663.

This is a summary of a paper given by Elliott before ARIBA Discussion of the principle of prestressing, of pretensioning and post-tensioning. Description of Freyssinet and Magnel's methods, structures, construction and economy.

D58 Evans, R. H., "Prestressed Reinforced Concrete", Journal of the Institute of Municipal Engineers (London), 1948, Vol. 74, No. 11, pp. 565-596.

This paper has a short historical introduction; explanation of basic principles of prestressing; design formulas for working load design; discussion of present day knowledge of such subjects as creep, shrinkage and bond; and a short discussion of applications of prestressed concrete.

D59. Richart, F. E., "Advances in Reinforced Concrete During the Past Quarter of Century", Proceedings, American Concrete Institute, 1948, Vol. 44, No. 8, pp. 720-731.

Very brief statement of development and future possible uses on pp. 727-728.

1949

D60. Anderson, F., "Reinforced Concrete with Special Reference to Prestressed Concrete", Journal of the Institution of Municipal Engineers (London), 1949, Vol. 76, No. 3, pp. 257-268.

Subjects discussed: history of prestressed concrete, various systems of prestressing, losses in prestress due to creep, shrinkage and slipping of wires, quality requirements for materials, advantages of prestressing and structures built.

D61. Campus, F., "Le béton précontraint", Revue Universalle des Mines de la Metallurgie des Travaux Publics (Liege), 1949, 9th Series, Vol. 5, No. 12, pp. 421-436.

Description of the basic principles of prestressed concrete, its design, some tests and numerous examples of actually built structures.

D62. Caquot, A., "Les bases scientifiques de la précontrainte", Travaux (Paris), 1949, Vol. 153, No. 178, pp. 311-312.

This paper is based on the opening speech made before the Scientific Association of Prestress and gives some history of the development of prestressed concrete. Brief discussion of the behavior of prestressed concrete and description of some methods of prestressing.

D63. Dischinger, F., "Weitgespannte Tragwerke", Der Bauingenieur (Berlin), 1949, Vol. 24, No. 7, pp. 193-199; No. 9, pp. 275-280; No. 10, pp. 308-314.

Creep is discussed with respect to pretensioning and post-tensioning; construction of arches, domes, and shells of prestressed concrete is discussed. Prestressed trusses and girders prestressed according to Finsterwalder's principles are discussed.

D64. Freyssinet, E., "Evolution du rôle des précontraintes dans les constructions et conséquences de leur utilisation systématique", Travaux (Paris), 1949, Vol. 33, No. 178, pp. 313-321.

A good discussion of the problems of prestressed concrete.

D65. Freyssinet, E., "Observations sur le béton précontraint", Travaux (Paris), 1949, Vol. 33, No. 172, pp. 47-70.

Very good review of Freyssinet's work in development, promoting and use of prestressed concrete.

This same article can be found in U. of I. library also under q. 693.5 B465 (a reprint containing both Lalande's paper "Diversité des application du béton précontraint" Travaux 1949, No. 171, and this paper).

D66. Lalande, M., "Diversité des application du béton précontraint", Travaux (Paris), 1949, Vol. 33, No. 171, pp. 2-22.

Description of Freyssinet method of prestressing and his anchorages, description of existing structures, construction and manufacturing processes.

Can be found in University of Illinois library also under number q693.5, B465 (this is a reprint containing both this and Freyssinet's paper "Observations sur le béton précontraint", Travaux 1949, No. 172.)

D67. Thomas, F. G., "Prestressed Concrete", Proceedings of the Conference held at the Institution, Institute of Civil Engineers, (London), 1949.

This paper is a review of the present day state of development of prestressed concrete. Methods of design are presented in general terms as well as the methods of prestressing and construction. Examples of existing structures are given and data on a great number of such structures compiled in tabular forms. One relatively short chapter is devoted to the experimental work.

D68. Walsh, H. V.; Cefola, A., "Prestressed Concrete", Architectural Record, 1949, Vol. 106, No. 2, pp. 136-142.

Discussion of the basic principles and behavior of prestressed concrete and photographs of European bridges and buildings. Written for architects.

D69. Walter, E., "Pioneer Overlooked", Engineering News Record, October 20, 1949, Vol. 143, No. 16, p. 100; Reader Comment Section.

In this discussion of Coff's paper (ENR, September 1, 1949) the author points out that Karl Wettstein received a patent in 1921 and manufactured prestressed concrete slabs pretensioned with piano wire. The planks were manufactured in various plants.

1950

D70. Abeles, P. W., "Further Notes on the Principles and Design of Prestressed Concrete", Civil Engineering and Public Works Review (London), 1950, Vol. 45, 1951, Vol. 46

Part 1:	No. 529, pp. 443-445		6:	No. 535, pp. 38-40
Part 2:	No. 530, pp. 508-512		7:	No. 537, pp. 187-190.
Part 3:	No. 531, pp. 579-581		8:	No. 538, pp. 262-264
Part 4:	No. 532, pp. 657-662		9:	No. 540, pp. 439-442
Part 5:	No. 533, pp. 728-731		10:	No. 541, pp. 524-526
			11:	No. 544, pp. 775-778
			12:	No. 545, pp. 861-864

Discussion of the behavior of prestressed concrete beams with reference to the sustained load tests conducted by the Ministry of Works; Discussion of the moment resisting capacity of prestressed concrete beams with procedure for calculating the ultimate capacity of such beams; Partial prestressing discussed. Design. Shear reinforcement. Composite beams. Floor systems.

D71. Dobell, C., "Patents and Codes Relating to Prestressed Concrete", Proceedings, American Concrete Institute, 1950, Vol. 46, No. 9, pp. 713-724.

A compilation of patents in US and abroad that deal with or are related to prestressing. A short discussion of Billig's proposed code.

Discussion by J. J. Polivka regarding earlier work in prestressing omitted by Dobell.

D72. Freyssinet, E., "Prestressed Concrete: Principles and Applications", Journal Inst. of Civil Engineers (London), 1950, Vol. 33, No. 4, pp. 331-380.

Brief history of Freyssinet's work in prestressed concrete. Reasons for prestressing, behavior of and properties of prestressed concrete and factors of safety are discussed. Discussion of various methods of manufacture aimed at obtaining high-strength concrete, of methods of prestressing and anchoring the wires, and of creep of steel is also included. Description of some of the structures designed by Freyssinet.

D73. Freyssinet, E., "Souvenirs", Beton-und Stahlbetonbau (Berlin), 1950, Vol. 45, No. 2, pp. 26-31.

A speech made by Freyssinet in Paris in commemoration of the invention of reinforced concrete. He reviews the work he has done in prestressed concrete.

D74. Freyssinet, E., "Theory and Application of Prestressed Concrete", The Municipal Journal, London, 1950, Vol. 58.

A series of articles entitled:

1. A gamble with concrete and prestressed won (A revolution in construction work) No. 2969, pp. 31-32.
2. What makes prestressed structures different? (Novel behavior and properties of prestressed concrete), No. 2970, pp. 99-101.
3. A catechism for prestressed concrete (From theory to practice), No. 2971, pp. 170-171.
4. How prestress is created, No. 2972, pp. 241.
5. Thirty years of anchorage research (Theory and application of prestressed concrete) No. 2973, pp. 310-311.
6. Prestressing makes water leakage a thing of the past (Theory and application of prestressed concrete), No. 2974, p. 381.
7. Bridges-Harbours-Runways (Theory and Application of prestressed concrete) No. 2975, p. 455, 457.

History of prestressed concrete (Freyssinet Method), theory, method of prestressing, examples of uses, extreme possibilities and making of high strength concrete are discussed. Opinion is expressed that after permanent deformation takes place in the steel, a prestressed concrete beam behaves as an ordinary reinforced concrete beam.

D75. Germundson, T., "Prestressed Concrete Construction Procedures", Proceedings, American Concrete Institute, 1950, Vol. 46, No. 10, pp. 857-876.

History of prestressing. Explanation of various methods of prestressing. Description of plants producing precast prestressed members. Description of various structures of prestressed concrete.

D76. Hammond, R., "Basic Principles of Prestressed Concrete", Machinery Lloyd (London), 1950, Vol. 22, No. 20, pp. 68-81.

This paper includes a very good historical review of the development of prestressed concrete. Methods of prestressing are discussed as well as the future potentialities and manufacturing techniques.

D77. Hammond, R., "Prestressed Concrete", Architectural Design (London), 1950, Vol. 20, No. 1, pp. 8-9.

Brief historical review, description of a few methods of prestressing and description of some existing structures.

D78. Levi, F., "Nouvelles recherches sur les constructions précontraintes", La Ricerca Scientifica (Rome), 1950, Vol. 20, No. 12, pp. 1846-1849.

Description of an airport runway slab built of prestressed concrete in Italy. Losses in prestress discussed.

D79. Prempain, "Quelques réflexions sur les journées techniques de la précontrainte", Travaux (Paris), 1950, Vol. 34, No. 183, pp. 39-40.

A review of the work done in prestressed concrete.

D80. Roessinger, F., "Generalites Sur Differents Modes de Precontrainte du Beton", Bulletin Technique de la Suisse Romande (Lausanne), August 26, 1950, Vol. 76, No. 17, pp. 225-237.

This paper discusses the following topics: conditions of stress in prestressed beam; principles of prestressing both with bonded wires and with cables; creep and shrinkage; prestressing techniques; manufacturing prestressed elements by the long line process; manufacturing larger elements utilizing post-tensioned grouted cables; and applications of prestress in North Africa which includes bridges, pipes, and masts.

D81. Rüsch, H., "Framsteg inom betonbyggnadstekniken", Betong (Stockholm), 1950, Vol. 35, No. 4, pp. 257-289.

Short historical summary is followed by a discussion of the principles which should be considered in the design of prestressed concrete structures. Different methods of anchoring the prestressing wires are mentioned and some existing structures described.

D82. - - -, "Developments in Prestressed Concrete", Concrete and Constructional Engineering, (London), 1950, Vol. 45, No. 12, pp. 415-417.

The author discusses generally some of the developments in prestressed concrete. He thinks the notation and symbols concerning the subject should be standardized. He criticizes some of the assumptions used in design such as constant modular ratio and actual steel stresses at beam failure for bonded prestress Expresses belief that prestressed concrete is economical and enough is known about it that it may safely be used extensively.

D83. - - -, "Prestressed Concrete" Reinforced Concrete Review (London), 1950, Vol. 2, No. 1, pp. 12-28.

This paper makes reference to several other papers and has abstracts from papers by Magnel and Freyssinet dealing with methods of prestressing and anchoring, with the behavior of prestressed concrete, with materials, and with applications. The paper is fairly good from the standpoint of presenting much general information in a condensed form.

1951

D84. Birdsall, Blair, "Prestressed Concrete", John A. Roebling's Sons Company, Trenton, New Jersey 1951, Reprint of a speech.

Discussion of the basic concepts of prestressing. Description of the jointless slab built in a Roebling's warehouse in Chicago and a suspension bridge with prestressed concrete floor over Rio Paz (El Salvador, Guatemala). Describes various model beams tested to failure.

D85. Caughey, R. A., "Wanted: Guide in Developing Prestressed Concrete", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 7, pp. 561-562. Letters from Readers Section.

Request from Caughey that ACI publish progress reports on development of prestressing which may be used as a guide until enough knowledge is accumulated to write a code.

D86. Corning, L. H., "Why Prestressed Concrete?", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 2-8.

Discusses the advantages of prestressed concrete with respect to cracking, use of high strength materials, deflections, size of members, and construction economy. Expresses the desirability of having design specifications.

D87. Corning, L. H., "Why Prestressed Concrete?", Civil Engineering 1951, Vol. 21, No. 10. pp. 41-45.

A general discussion of the place of prestressed concrete in the US construction. This article is based on a paper presented before the First US Conference on Prestressed Concrete, MIT 1951.

D88. Crom, T. R., "Processes and Patents in Prestressed Concrete", Proceedings of the Second Annual Structural Engineering Conference, Bulletin of the Florida Engineering Experiment Station 47, 1951, pp. 27-30.

Short discussion of the history of prestressed concrete, of methods of prestressing, anchorage and bond. Patents mentioned briefly in general terms, field of application discussed.

D89. Freyssinet, E., "Sur le rôle et l'importance des deformations non élastiques du béton précontraint", Travaux (Paris), 1951, Vol. 35, No. 196, pp. 200-202.

Review of Freyssinet's work which led to the development of prestressed concrete. Effect of creep is discussed. Freyssinet maintains that prestressed concrete is not related very closely to reinforced concrete.

D90. Guyon, Y., "Beton Precontraint - Etude Theorique et Experimentale", Editions Eyrolles, 1951, 692 pp.

This book treats the following main topics: Prestressing Techniques; Materials; Influence of friction on a post-tensioned curved cable; Resistance of prestressed concrete structural parts to fire; Stresses at the end of members caused by the prestressing

force; Bonded prestress; Design of beams with pretensioned and post-tensioned steel, with straight and curved reinforcement, and with uniform or non-uniform cross-section; Tests of beams; and factors of safety. One or more chapters are devoted to each of these main topics.

D91. Harris, J. D., "The Scope of Prestressed Concrete", Journal of the Institution of Municipal Engineers (London), 1951, Vol. 77, No. 7, pp. 547-558.

Ahistorical review is followed by description of various systems of prestressing and a list of several prestressed concrete structures built in Europe.

D92. Hirschtal, M., "Wanted: Guide in Developing Prestressed Concrete", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 7, p. 562. Letters from Readers Section.

Hirschtal asks for specification regarding the strength of prestressing steel. Expresses hope that some researchers will develope a method of prestressing through reaction against abutments (instead of using steel).

D93. Lazarides, T. O., "On the Combined Use of Pre-tensioning and Post-tensioning Methods", Magazine of Concrete Research (London), 1951, Vol. 2, No. 5, pp. 79-86.

Design principles and methods of construction are described. The author explains how pre-tensioning and post-tensioning can be used together effectively in order to prestress continuous members for both positive and negative moments.

D94 Meier, H., "Die neuen Spannbetonschwellen der Deutschen Bundesbahn", Beton-und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 8, pp. 174-180; No. 9, pp. 202-207.

This paper discusses the new railroad tie which is in service in the German R. R. built of prestressed concrete. Stresses under service conditions are discussed. Models were tested by photoelasticity, the results of which are discussed. Manufacturing process is described--18 mm. rods with threaded ends are used for prestressing. Ends of rod are anchored with washer anchor plate.

D95. Menefee, F. N., "Wanted: Guide in Developing Prestressed Concrete", Proceedings, American Concrete Institute, 1951, Vol. 47, No. 9, pp. 751-752.

This is an answer to Caughey and Hirschtal, (dtto, No. 7). Menefee reviews what ACI has done along these lines and discusses the properties of prestressing wire.

D96. Pacholik, L., "Předpjatý beton a zprumyslnění stavebnictví", (Prestressed Concrete and Industrialization of Building Construction), Stavební prumysl (Prague), 1951, Vol. 1, No. 15, pp. 337-346.

General paper discussing the design principles and advantages of prestressed concrete. Sketches of cross sections of prestressed concrete bridges for various span length are given and construction methods discussed shortly.

D97. Spronck, M., "Prestressed Concrete: Its Future in the United States", Contractors and Engineers Monthly, August, 1951, Vol. 48, No. 8, pp. 3, 84-91.

This article discusses the advantages, disadvantages, and the features of prestressed concrete; the various methods of prestressing; discusses the Madison Co., Tenn. Bridge and the Walnut Lane Bridge, and various European structures.

D98. Stilliman, J. W., "The Theory and Practice of Prestressed Concrete", U. S. Navy Civil Engineer Corps Bulletin, 1951, Vol. 5, No. 61, pp. 336-344.

General description of prestressed concrete, design, methods of prestressing.

D99. Veit, O., "Vorspannung im Stahlbeton," Beton und Stahlbetonbau (Berlin), 1951, Vol. 46, No. 1, pp. 13-17.

Discussion of the basic concept of prestressed concrete. Formulas are given for members subject to tension and for members subject to bending.

D100. Winter, G., "Teaching of Prestressing", Engineering News Record, November 1, 1951, Vol. 147, No. 18, p. 65. Reader Comment Section.

The author suggests that the fundamentals of the design of prestressed concrete members should be taught as a part of the general undergraduate concrete course. More detailed information might be included in an advanced course. Winter supports the ideas expressed by Feld in ENR, October 11, 1951, p. 48.

D101. - - -, "New Ways with Concrete", Fortune, August, 1951, Vol. 44, pp. 106-116.

Part of this paper is devoted to a discussion of prestressed concrete construction in the U. S. The Walnut Lane Bridge; Madison Co., Tenn., Bridge; Fayetville, Tenn. high school stadium; and circular tanks prestressed by the Preload Corporation are mentioned.

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A75, C2, C5, C7, C20, C21, E33.

E. Circular Structures.

1923-1935

E1. Hewett, W. S., "A Method of Constructing Reinforced Concrete Water Tanks", Proceedings, American Concrete Institute, 1923, Vol. 19, pp. 41-52.

This is believed to be the original Hewett's paper on prestressing water tanks circumferentially to prevent leakage and eliminate tensile stresses in concrete. Mild steel with turnbuckles.

E2. Jensen, J. A., "Shell of Concrete Standpipe Prestressed by Steel Hoops", Engineering News Record, February 16, 1933, Vol. 110, No. 7, pp. 224-225.

110 ft. high water tower is prestressed both vertically and circumferentially by means of turnbuckles on steel rods. Prestress was only 18,000 psi.

E3. Crepps, R. B., "Investigation of Stresses in Prestressed Reinforced Concrete Pipe", Engineering Bulletin, Purdue University, Research Series No. 46, 1934.

Tests of three pipes (diameter 30", 42", 60") prestressed longitudinally and circumferentially. Tested under internal water pressure until cracks opened. Complete information given.

E4. Kuranz, A. P., "Prestressed Concrete Standpipe Built in Vertical Panels at Waukensha, Wisconsin", Engineering News Record, April 4, 1935, Vol. 114, No. 14, pp. 488-489.

Description of a water tank built by the Hewett system. It was built in vertical panels rather than in horizontal rings.

1936

E5. Crom, J. M., "Prestressed Reinforcement for Domed Concrete Tank", Engineering News Record, April 16, 1936, Vol. 116, p. 555.

Domes of tanks 60 ft. in diameter carrying a central load of 20 tons. Prestressed with smooth round rods with upset ends coupled together into an endless band at the periphery of the dome.

E6. Hewett, A. L., "Water Tanks of Reinforced Concrete", Journal, American Water Works Assoc., 1936, Vol. 28, No. 1, pp. 43-49.

Describes the Hewett system of prestressing and gives examples of structures built. (This author is not the man who originated the Hewett system)

E7. Mary, M., "Pressure Pipes for the Mareges Hydroelectric System", Int. Assoc. Bridge and Struct. Eng., Second Congress, Preliminary Publications, Berlin 1936, (W. Ernst), pp. 1211-1231.

Method of prestressing of large size built-in-place pipes is described. The method described is applicable also for prestressing above the ground.

1937-1938

E8. - - -, "Schachtausbauten aus Spannbeton", Beton und Eisen (Berlin), 1937, Vol. 36, No. 17, pp. 281-282.

Description of use of prestressed concrete in tunnel construction.

E9. Kleinlogel, A., "Eisenbeton-Druckrohre als Schleuderbeton- und als Schleuderbeton-Vorspannrohre", Beton und Eisen (Berlin) 1938, Vol. 37, No. 10, pp. 161-166.

This article deals with the manufacturing of prestressed concrete pipes and compares its qualities with non-prestressed, precast, concrete pipes.

1939

E10. - - -, "Prestressed Reinforcement in Reservoirs and Tanks", Concrete and Constructional Engineering (London), 1939, Vol. 34, No. 1, pp. 81-86.

The theory of prestressing as applied to circular tanks subjected to hydraulic pressure is explained. Method of calculating required stress in prestress rods is explained. Included is description of actual 62 ft. diameter tank.

E11. - - -, "Principle of Prestressed Reinforcement in Design of Dome", Concrete, (Chicago), 1939, Vol. 47, No. 2, pp. 3-4.

Hewett method was used to prestress the dome of clarifier tank in St. Paul. 21- 1.365"ø were used to prestress the dome. They were placed around dome ring and tightened with turnbuckles. Elementary discussion of theory is included.

E12. - - -, "Reinforced Concrete Shell Dome is Intact After Terrific Explosion", Concrete, (Chicago), 1939, Vol. 47, No. 11, pp. 3-4.

A water tank 135 ft. in diameter prestressed by the Hewett system had also a prestressed dome. During construction (nearly completed) an explosion occurred inside the tank which lifted the dome 18-24 in. into the air. The dome is still structurally sound, but did develop several radial cracks and 2 annular cracks.

1940

E13. Kennedy, R. C., "Prestressed Concrete Tank Features, Special Details", Western Construction News, 1940, Vol. 15, No. 4, pp. 130-132.

Description of prestressing techniques used on construction of water tank. Tank prestressed by Hewett system.

E14. - - -, "Huge Reinforced Concrete Foundation is a Feature of Big Reservoir", Concrete (Cement Mill Edition), (Chicago), 1940, Vol. 48, No. 3, pp. 3-4, 44.

Describes design and construction of large water storage tank. Prestressed with rods in accordance with W. S. Hewett system.

1941

E15. - - -, "Prestressed Concrete Water Tanks," Engineering News Record, March 13, 1941, Vol. 126, No. 11, pp. 419-421.

Water reservoirs of prestressed concrete are described. Walls are poured in vertical panels. Every 40 ft. along circumference is a steel column to which the prestressing rods are anchored. Rods are only stressed to 25,000 or 30,000 psi. Domes are prestressed around their periphery.

E16. - - -, "Unique Features Mark Design and Erection of Mammoth Concrete Water Tower," Concrete, (Chicago), 1941, Vol. 49, No. 11, pp. 2-4.

Water tank 70 ft. diameter elevated 8 ft. above ground; designed by W. S. Hewett method. Supported by 3 concentric concrete cylinders. Dome roof is not prestressed.

1942

E17. Hadley, H. M., "Concrete Storage Tanks", Pacific Builder and Engineer (Seattle), 1942, Vol. 48, No. 9, pp. 30-36.

Discussion of three types of concrete tanks and of their relative merits. Type of tanks: reinforced concrete, prestressed concrete - Hewett method, prestressed type without turnbuckles.

E18. Lenk, K., "Spannbetonrohre", Beton und Eisen (Berlin) 1942, Vol. 41, Nos. 15-16, pp. 137-44.

Description of the manufacturing process of large prestressed concrete pipes and discussion of the problem of joining the section in the field.

E19. - - -, "Council Bluffs Builds Twin Reservoirs of Prestressed Reinforced Concrete", Concrete, (Chicago), 1942, Vol. 50, No. 4, p. 2.

Two prestressed concrete reservoirs of 106 ft. diameter and 30 ft. height were being built at the time of this article. They were designed by W. S. Hewett using steel rods tightened with turnbuckles. Dome ring was also prestressed. No technical information supplied.

E20. - - -, "Prestressed Concrete Water Tanks", Engineering News Record, April 23, 1942, Vol. 128, No. 17, pp. 608-609.

Two 106 ft. diameter tanks designed by W. S. Hewett are built in Council Bluffs, Iowa. Prestressed with round rods tightened with turnbuckles. Dome is prestressed with 9 rods around its ring. No technical information given.

1943

E21. Crepps, R. B., "Wire-Wound Prestressed Concrete Pressure Pipe," Proceedings, American Concrete Institute, 1943, Vol. 39, No. 6, pp. 545-555.

Tests, theory and manufacturing procedure of circumferentially prestressed concrete pipes. Stress in circumferential wire: 100,000 psi. Design theory is presented. Both hydrostatic pressure tests and 3 edge loading tests are discussed and results given.

E22. Crom, J. M., "High Stressed Wire in Concrete Tanks, Engineering News Record, December 30, 1943, Vol. 131, No. 27, pp. 947-949.

Describes the machine for wraping of the high strength wire around a tank. Discusses failures of tanks due to loss of prestress.

E23. Garrabrant, R. B., "Navy Builds Prestressed Concrete Fuel Tanks", Engineering News Record, January 28, 1943, Vol. 130. No. 4, pp. 135-137.

During the war the Navy built several fuel storage tanks with walls prestressed with circular rods. Prestressing accomplished with turnbuckles. Minimum yield point of rods, 50,000 psi.

E24. - - -, "New Method Used to Make Prestressed Concrete Pipe (Wire-wound)", Engineering News Record, September 23, 1943, Vol. 131, No. 13, pp. 476-478.

Describes construction of wire wound concrete pipe to conduct water under pressure.

E25. - - -, "Prestressed Concrete Pipes by a New Manufacturing Method", Engineering News Record, December 16, 1943, Vol. 131, No. 25, pp. 885-887.

Process used by Lock Joint Company in manufacturing prestressed pipes. Concrete is centrifically placed and steam cured. Wire is wrapped on from a spool while pipe is spinning. High tensile stress is used.

E26. - - -, "Prestressed Concrete Reservoirs: Concrete Poured in 8 ft. Lifts", Concrete and Constructional Engineering, (London) 1943, Vol. 38, No. 3, pp. 104-105.

Description of 106 ft. diameter tank in Iowa designed by W. S. Hewett. 1.375 in. rods with turnbuckles were used to prestress.

1944

E27. - - -, "Merry-go-round Machine Applies High Tensile Steel Wire to Prestressed Concrete Tanks", Construction Methods, 1944, Vol. 26, No. 1, pp. 60-61 and 132-134.

Describes the Preload Corporation method of prestressing cylindrical tanks with high strength wire tensioned by a die which travels around the tank wrapping it with this continuous wire.

1945

E28. Carr, J. R., "Two-way Prestressed Concrete Water Storage Tank", Engineering News Record, October 4, 1945, Vol. 135, No. 14, pp. 434-439.

Description of a 4,750,000 gal. tank prestressed both in circumferential and vertical direction. 1-3/8" diameter and 1-1/4" diam. rods were prestressed to 32,000 psi with the aide of turnbuckles. These were retightened after 6 months.

E29. Crowley, J. J., "Prestressing Bands on a Concrete Tank", Engineering News Record, May 3, 1945, Vol. 143, No. 18, pp. 636-638.

3/4" square bars were used in prestressing a 300,000 gal. water tank. Some difficulty was encountered in measuring the amount of prestress - it was overcome by use of a shear wrench.

E30. Hart, P. P., "Prestressed Concrete Tank in Miami", Concrete (Chicago), 1945, Vol. 53, No. 7, pp. 18-19, 23.

A large water-tank built of prestressed concrete. Prestressed design was cheaper than other designs considered.

E31. Kennedy, R. C., "Design and Construction of Prestressed Concrete Tanks", Journal, American Water Works Association, 1945, Vol. 37, No. 1, pp. 73-83.

Description of prestressed concrete tanks built by the Hewett system. Equations for finding the amount of needed prestress. Techniques of building and prestressing are described.

E32. Longley, F. F., "Prestressed Reinforced Concrete Pipe", Journal, New England Water Works Association, 1945, Vol. 59, No. 4, pp. 335-347.

Description of the manufacture of lock-joint pressure pipes prestressed with high strength wire. Centrifugal placing of concrete.

E33. Mautner, K. W., "Prestressed Concrete in Structures of Annular Cross Section", Structural Engineer (London), 1945, Vol. 23, No. 3, pp. 117-163, No. 9, pp. 437-451.

A rather complete treatise on manufacture of prestressed concrete pipes and tanks. Several methods are explained and their relative merits discussed. Listeners to this paper took part in the discussion during which a number of questions on the general subject of prestressing were answered by Mautner.

E34. Ross, C. W., "Tests of Prestressed Concrete Pipes Containing a Steel Cylinder", Proceedings, American Concrete Institute, 1945, Vol. 42, No. 1, pp. 37-48.

Description of pressure and bending tests on prestressed concrete pipes with steel inside lining.

E35. - - -, "A Large Prestressed Concrete Water Tank", Concrete and Constructional Engineering (London), 1945, Vol. 40, No. 12, pp. 268-269.

Water storage tank in Great Falls, Montana.
Same as "Large Water Storage Tank is Prestressed", in Concrete, (Chicago, 1945, Vol. 53, No. 10, pp. 2-3.

E36. - - -, "Large Water Storage Tank is Prestressed", Concrete, (Chicago), 1945, Vol. 53, No. 10, pp. 2-3.

Water storage tank at Great Falls, Montana. Floor is prestressed to couteract radial stresses caused by horizontal expansion and elongation of walls by water pressure. Wall is prestressed with rods tightened with turnbuckles to 30,000 psi.

1947

E37. Doull, R. M., "Reconstruction of Halifax Water Reservoir," Engineering Journal (Montreal), 1947, Vol. 30, No. 5, pp. 211-215.

Description of the reconstruction of water reservoir in Halifax. New roof of prestressed concrete shell described.

E38. Doull, R. M.; Kline, J. D., "Prestressed Concrete Shell Dome Features Rebuilt Halifax Reservoir", Engineering News Record, August 7, 1947, Vol. 139, No. 6, pp. 187-191.

Description of the repair of an old reservoir.

E39. Doull, R. M.; Kline, J. D., "Reconstruction of the Halifax High Service Reservoir", Journal, American Water Works Assoc., 1947, Vol. 39, No. 6, pp. 503-514.

Similar to the article "Prestressed Concrete Shell Dome Features Rebuilt Halifax Reservoir" published by the same authors in Engineering News Record, 1947.

E40. Fornerod, M. F., "Prestressed Concrete Shell Roof Construction", Int. Assoc. Bridge and Struct. Eng., Publications Vol. 8, Zurich 1947, pp. 91-103.

Design theory and discussion of the influence of prestressing on the design of shallow spherical concrete shells. Description of the Preload method of prestressing large tanks.

E41. - - -, "New Method of Prestressing Concrete Pipes", Concrete and Constructional Engineering, (London), 1947, Vol. 42, No. 7, p. 216.

Describes the "Rocla" method of prestressing which originated in Australia. After concrete is placed centrifugally and the wire placed but not stressed, the inner form of the pipe is expanded. The outer form also expands slightly. This puts steel in tension, concrete in compression, and squeezes excess water out of concrete.

E42. - - -, "Prestressed Concrete Pipe", Concrete, (Chicago), 1947, Vol. 55, No. 9, p. 38.

Rocla method of prestressing pipe with expandable molds. Both interior and exterior molds are expandable. Pressure is applied to interior mold. This compresses the concrete and squeezes out excess water while simultaneously tensioning the wires.

1948

E43. Doull, R. M., "Big Prestressed Pipe Without Liners", Engineering News Record, June 24, 1948, Vol. 140, No 26, pp. 1010-1015.

84" diameter concrete pipes prestressed in the same manner as a water tank.

E44. Freyssinet, E., "Ouvrages en béton précontraint destinés à contenir ou à retenir des liquides", Int. Assoc. Bridge and Struct. Eng., Third Congress, Preliminary Publications, Liége, 1948, pp. 343-360.

Freyssinet describes the manufacture of prestressed concrete pipes prestressed both longitudinally and transversally. Cubical reservoirs and vats. Application of prestressing to dams - vertical cables anchored in the subsoil. Structures subjected to exterior water pressures - tunnels, caissons, pontoons, etc.

E45. Lebelle, P., "Réservoir de 7.000 m^3 destiné à l'alimentation de le ville d'Orléans en eau potable", Int. Assoc. Bridge and Struct. Eng., Third Congress, Preliminary Publication, Liege, 1948, pp. 361-366.

Description of the water reservoir at Orleans, France. Prestressed by Freyssinet process in all directions.

E46. - - -, "Laying 60 Miles of Prestressed Pipe", Engineering News Record, May 13, 1948, Vol. 140, No. 20, pp. 708-711.

Description of manufacturing and laying of pipes prestressed circumferentially.

1949

E47. Dobell, C., "Design, Construction and Uses of Prestressed Concrete Tanks", Public Works, October, 1949, Vol. 80, pp. 45-48.

General reference on prestressed concrete tanks.

E48. - - -, "Making Unique Prestressed Concrete Pipe", Construction Methods, 1949, Vol. 31, No. 12, pp. 58-61.

54" by 16'-0" pipe manufacturing process. A series of photographs tell the story. Main feature of the prestressing is that it is spirally wound into a basket weave pattern thus stressing in two directions simultaneously. Similar article appears in Engineering News Record, October 6, 1949, Vol. 143, No. 14, pp. 24-26.

E49. - - -, "New Casting and Prestressing Technique for Ultra Strong Concrete Pipe", Engineering News Record, October 6, 1949, Vol. 143, No. 15, pp. 24-26.

54" by 16'-0" pipe manufacturing process explained. Main feature is that the circumferential prestressing wire is put on spirally (or basket weave pattern) to prestress it in two directions simulteneously.

E50. - - -, "Preload Tanks", Preload Enterprises, New York, 1949.

Primarily an advertising pamphlet describing the evolution of prestressed concrete and design and construction of prestressed concrete tanks.

1950

E51. Crom, J. M., "Design of Prestressed Tanks", Proceedings American Society of Civil Engineers, 1950, Vol. 76, Separate No. 7.

This paper gives data for evaluating shrinkage and plastic flow of concrete and describes methods that make practicable the use of the high strength cold-drawn steel wire.

E52. - - -, "Prestressed Concrete Sewer Tunnels Near Paris", Concrete and Constructional Engineering (London), 1950, Vol. 45, No. 11, pp. 404-407.

This tunnel is 13'-6" diameter and was precast in small pieces. A hoop of 0.2 in stainless steel 10" wide was placed around each ring of voussoir. Then the ring was expanded with jacks until desired tension was in the steel rim and wedges inserted to hold this stress. This erection and prestressing operation is described in detail. Freyssinet was consulting engineer.

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E53. Dobell, C., "Prestressed Concrete Tanks", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 9-20.

Discusses the history of the development of prestressed concrete as applied to use in tanks, discusses the design, construction and methods of prestressing. Paper is augmented with several pictures.

E54. Hendrickson, J. G., "Prestressed Concrete Pipe", Proceedings of the First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, August, 1951, pp. 21-29.

Discussion of manufacturing, uses, and design of prestressed concrete pipes, augmented with historical notes.

E55. Indri, E., "La conduit forcée en béton précontraint de l'usine hydro-électrique de Soverzene", Travaux (Paris), 1951, Vol. 35, No. 196 pp. 244-246.

This paper deals with the design and fabrication of prestressed concrete pipes used at the hydroelectric plant at Severzene.

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